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Introduction to Avionics Flight Test

Introduction aux Essais des Systémes D'armes

by

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Preface

Lieutenant General "Jimmy Doolittle" is most often remembered for his famed raid on Japan using B-25 aircraft launched from the deck of the Navy aircraft carrier *Hornet*; however, this amazing man's contributions to aviation hardly ended there. Besides being the first person to be awarded a Sc.D. in Aeronautical Science from the Massachusetts Institute of Technology, he was arguably the father of the discipline that is now called Avionics. He placed the first instrument flight equipment in an aircraft, performed the first long distance flight using instruments alone and even performed the first instrument approaches [ref. 58]. It seems likely; however, that even he could not have imagined the proliferation of avionics equipment in modern aircraft, particularly military aircraft.

Modern military aircraft rely heavily on highly complex electronic systems to make them effective weapons in a world filled with equally sophisticated counter systems. These components can add up to as much as 80% of the aircraft price tag. As new systems are developed, numerous tests are necessary to provide feedback in the iterative design process and to ensure that design parameters are met. Unfortunately, little has been written on the techniques for testing these systems. Even today, test pilot training programs stress aircraft performance and handling qualities testing while the majority of test work revolves around avionics testing. This book is an attempt to put in print the rudimentary knowledge necessary for a test pilot or engineer to develop and execute a cost effective and quick test of a modern avionics system.

Preface

Le general "Jimmy Doolittle" est plus souvent connu pour son fameux raid sur le Japon à bord d'un B25 lancé du porte avions Hornet, cependant, la contribution de cet homme remarquable à l'aviation ne s'arrete pas là.

Non seulement première personne à avoir recu un doctorat en sciences aéronautiques du MIT, il est sans conteste le pére de cette discipline que l'on appelle maintenant l'avionique. Il a le premier équipé un avion pour le vol aux instruments, effectué le premier vol longue distance en volant uniquement aux instruments et même effectué les premières approches aux instruments (ref 58). Il semble probable malgre tout qu'il n'aurait pu imaginer l'essort de l'avionique dans les avions modernes, particulierement les avions d'armes.

Les avions militaires modernes dépendent largement de systèmes électroniqes complexes pur les rendre efficaces dans un monde rempli de systèmes adverses également sophistiqués. Ces systèmes peuvent représenter jusqu'à 80% du prix de l'avion. Au fur et à mesure du dévelopment de ces systèmes, de nombreux essais deviennent nécessaires pour assurer un retour d'information dans le processus itératif de conception et pour sissurer que les spécifications sont remplies. Malheureusement, il y a peu d'écrits sur ces techniques d'essais. Même aujourd' hui, les programmes d'instruction des pilotes d'essais insistent davantage sur les aspects performances et qualités de vol alors que l'essentiel des essais en vol concerne les systèmes avioniques. Ce manuel est une tentative pour décrire les connaissances de base utiles ă un pilote ou ă un ingenieur d'essais pour concevoir et exécuter un programme d'essais de ces systèmes modernes qui soit rapide et d' un bon rapport qualité-coût.

FOREWARD

This book is intended as an introductory document to the subject of avionics flight testing. The target reader is the novice tester, desiring an initial exposure to the subject. Reference is made throughout the book to more in-depth documents, where they exist. In practical application, the new tester should use this book as a primer and then refer to the more detailed documents relating to the class of avionics under test or to the experience of more senior testers.

The first chapter provides a detailed discussion of the content and utility of the book. Chapters two through five provide a discussion of the theory and techniques for testing airborne air-to-air and air-to-ground radar, airborne navigation systems, electro-optical systems, and stores management sets, respectively. Each chapter begins with an introduction to the theory of operation of each class of system with sufficient detail to understand the test techniques which are next presented. Each test technique is developed in a largely self-contained fashion. Chapter six is a discussion of general considerations for developing a flight test profile combining some number of the previously described techniques. Chapter seven is a detailed case study and chapter eight includes some conclusions and recommendations.

As mentioned above, this book is intended as an introductory document for the novice. As such, caution should be exercised when directly applying the techniques provided here. Further research is warranted in most cases including more advanced documents relating to the theory and testing of the class of avionics in question. Chapter one points out that adequate references do not exist for every class of avionics, in these cases, it is important to search out persons with practical experience in testing similar systems.

ACKNOWLEDGEMENTS

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ACRONYMS, SYMBOLS AND ABBREVIATIONS

A=antenna capture Area

a=local speed of sound

ACM=Air Combat Maneuvering

ACP=Armament Control Panel

AGARD=Advisory Group for Aerospace Research and Development

AGL=Above Ground Level

ALT=ALTitude to begin air-to-ground resolution array test run

AMTI=Airborne Moving Target Indicator

avg_{lat}=average of the latitude of two radar targets

BIT=Built In Test

B_n=noise band width

$B_{scan\ deg}$=angular width of the B scan display in degrees

$B_{scan\ in}$=linear width of the B scan display in inches

CAD=Cartridge Activated Device

CAP=Combat Air Patrol

CPA=Closest Point of Approach

C=speed of light

CRT=Cathode Ray Tube

db=decibel

DBS=Doppler Beam Sharpening

DDL=Dispersive Delay Line

deg=degree

DEP=Design Eye Position

DLC=Delay Line Canceler

DME=Distance Measuring Equipment

DOD=Department of Defense
DR=Dead Reckoning

$drift_{\Delta h}$=measured angular horizontal drift

$drift_{\Delta v}$=measured angular vertical drift

$drift_h$=measured horizontal drift

$drift_v$=measured vertical drift

ECM=Electronic CounterMeasures

EHF=Extremely High Frequency

EO=Electro-Optical

ESM=Electronic Support Measures

EW=Electronic Warfare

f=frequency in hertz

FCS=Fire Control Set

f_{dt}=doppler shift due to target radial velocity

FL_c=focal length of the collimator (folded path length from target to mirror)

FLIR=Forward Looking Infrared Radar

FM=Frequency Modulation

F_n=noise figure

F_0=transmitted carrier frequency

FRL=Fuselage Reference Line

ft=feet

g=acceleration due to Gravity

G=directive gain of the antenna

GDOP=Geometric Dilution Of Precision

GHZ=Gigahertz

GPS=Global Positioning System

h=horizontal measurement of FLIR IFOV projected onto wall

H=altitude above the terrain in feet

HF=High Frequency

HOTAS=Hands On Throttle And Stick

h_{pc}=calibrated pressure altitude

HPD=Probability of Detection

h_{pi}=indicated pressure altitude

h_{po}=observed pressure altitude

HUD=Head Up Display

HZ=hertz

IFF=Interrogator Friend or Foe

IFOV=Instantaneous Field Of View

$IFOV_h$=Instantaneous Field Of View horizontal dimension

$IFOV_v$=Instantaneous Field of View vertical dimension

IFR=Instrument Flight Rules

IMC=Instrument Meteorological Conditions

in=inch

INS=Inertial Navigation System

IR=InfraRed

k=Boltzman's constant

KHZ=Kilohertz

KIAS=Knots Indicated AirSpeed

KOAS=Knots Observed AirSpeed

KW=Kilowatt

l=distance from FLIR aperture to crosshair intersection mark

l=distance to initial crosshair position for line of sight drift rate testing

L=receiver loss factor

LASER=Light Amplification through Stimulated Emission of Radiation

LED=Light Emitting Diode

LF=Low Frequency

LORAN=Long Range Navigation

LAT=the numerical average of the latitude of the two surveyed points

lb_f=pounds force

lb_m=pounds mass

m=meter

M=Mach number

MC=Mission Computer

MF=Medium Frequency

$M_{bearing}$=actual magnetic bearing from the flyover point to the radar target

MHz=megahertz

MIN=MINutes

MRΔT=Minimum Resolvable differential Temperature

MSL=Mean Sea Level

M_t=true Mach number

NFOV=Narrow Field Of View

nm=nautical mile

$NOTCH_{deg}$=angular width of the DBS notch

$NOTCH_{in}$=linear width of the DBS notch on the B-scan display

OAT_i=indicated Outside Air Temperature

OAT_o=observed Outside Air Temperature

P=transmitted power of the radar

PAL=Positive Arm Latch

PCA=Polar Cap Attenuation

PD=Probability of Detection

PMA=Program Manager for Aviation

PIREP=Pilot REPort of the weather

PPI=Planned Position Indicator

PPS=Pulses Per Second

P_{rep}=the TACAN derived range from the beginning of the peak of the sawtooth

PRF=Pulse Repetition Frequency

PRI=Pulse Repetition Interval

PW=Pulse Width

R=gas constant for air, 53.35 $(ft)(lb_f)/(lb_m)(^\circ R)$

rad=radians

Radar=Radio Detection and Ranging

R_b=target range at breakout

RF=Radio Frequency

$R_{horizon}$=radar horizon

r=angular resolution of the FLIR

rms=root meas square

R_{max}=maximum radar range

$R_{max\ unamb}$=theoretical unambiguous maximum range

R_{min}=theoretical minimum range

$R_{min\ res}$=theoretical minimum range resolution

R_{rep}=the TACAN derived range from the beginning of the peak of the sawtooth

R_{sf}=response of scanning FLIR

R_t=Range from the target

R_{target}=radar derived range to the targets

$R_{test\ begin}$=minimum range between test airplane and target for azimuth resolution testing

RΔT=Resolvable differential Temperature

S=across azimuth target Separation

SA=Selective Availability

SA=Situational Awareness

SEP=Spherical Error Probable

SF_{co}=cutoff Spatial Frequency

SF_{coa}=SF_{co} airborne

SF_{cog}=SF_{co} ground

SF_t=Spatial Frequency of the Target

SHF=Super High Frequency

SID=Sudden Ionospheric Disturbance

SMP=Stores Management Processor

SMS=Stores Management Set

S/N=Signal to Noise ratio

$(S/N)_{min}$=minimum signal to noise ratio

STT=Single Target Track

T=absolute temperature

t_a=ambient temperature

TACAN=Tactical Air Navigation

$T_{bearing}$=actual true bearing from the flyover point to the radar target

TEMP=Test and Evaluation Master Plan

TPC=Tactical Pilotage Chart

TWS=Track While Scan

UHF=Ultra High Frequency

v=vertical dimension of IFOV projected onto wall

V=magnetic variation

V&V=Validation and Verification

V_c=calibrated airspeed

V_i=indicated airspeed

VHF=Very High Frequency

VID=Visual Identification

VMC=Visual Meteorological Conditions

VLF=Very Low Frequency

V_o=observed airspeed

VS=Velocity Search

V_t=true airspeed

W=Watt

WP=WayPoint

W_{1c}=Width of one bar and one space in target template

WFOV=Wide Field Of View

Δ_{res}=measured angular resolution of the radar

Δh_{pic}=pressure altitude instrument correction

Δh_{pos}=pressure altitude position error correction

Δ_{Lat}=the difference between the latitude of the surveyed points in degrees

Δ_{Long}=the difference between the longitude of the surveyed points in degrees

Δnm=the difference in nautical miles between the surveyed points along the true north-south or east-west axis

ΔOAT_{ic}=Outside Air Temperature instrument correction

Δres=measured angular resolution

ΔT=temperature differential

ΔV_{ic}=airspeed instrument error correction

ΔV_{pos}=airspeed position error correction

γ=ratio of specific heats, 1.4

γ=aircraft flight path angle

λ=wavelength

μ=microns

μsec=microsecond

σ=radar cross section

σdesired=desired radar cross section

σtest=test target radar cross section

θ=test radar advertised antenna beam width

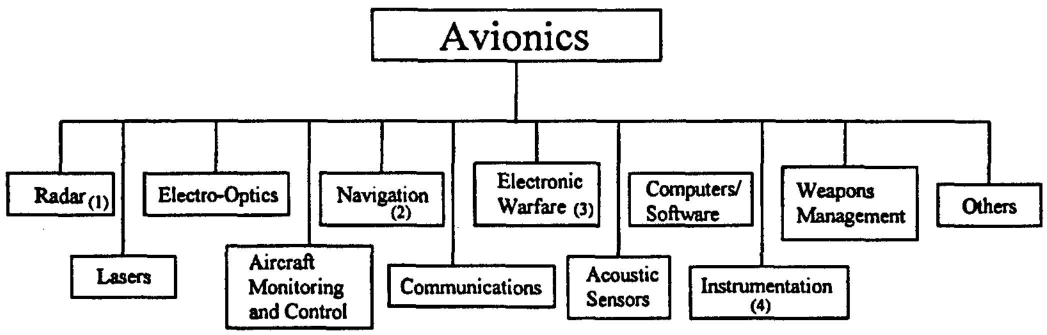
$^{\circ}$ =degrees

$^{\circ}$ R=degrees Rankine

1.0 INTRODUCTION

The purpose of this document is to provide a basic introduction to the topic of developmental[1] avionics flight test. The target reader is the novice, just being introduced to the subject, such as a student at one of the test pilot schools, or a person just beginning in the field. The paradigm used in constructing the book was the curriculum at the test pilot schools, particularly, the United States Naval Test Pilot School, which has an avionics flight test specialization. There are many similarities between the flight test techniques that follow and those taught at the schools.

Figure 1 provides one definition of the categories of systems included in the field of avionics. Unfortunately, space constraints do not allow discussion of all of these categories in one AGARD publication and thus three are singled out: radar, electro-optical and navigation. As at the test pilot schools, the teaching technique chosen here is demonstration. The intent is that if the student can be made to understand the development of the sample test techniques shown in this book, he or she can then extrapolate to different systems and platforms. A thorough understanding of the test development process has an added benefit. It is plausible that the tester may some day



(1) Ref 50 is a description of air-to-air radar test techniques.
(2) At the time of this writing, an AGARDograph was chartered providing a detailed description of radio navigation testing. Ref 52 is an excellent treatment of stand-alone Global Positioning System (GPS), hybrid GPS and fully coupled Inertial/GPS testing.
(3) At the time of this writing, an AGARDograph was being chartered covering the subject of Electronic Warfare testing.
(4) The volumes of AGARDograph 16 and 300 relating to instrumentation are included as references.

Figure 1: Categories of Avionics

[1] Developmental testing is performed as part of the iterative design process. Data derived from developmental testing is primarily intended to measure whether the system has met its intended functional requirements, and if not, to provide data useful to the designer for improving the design. Note that this type of testing is distinctly different from operational testing. Operational testing is performed by the intended users (vice professional testers and engineers) in the intended operational environment as a final "dress rehearsal" for the system. It is important for the developmental tester to remember that when he or she has determined that the system has completed the developmental phase of testing that it must then pass operational testing. This operational requirement will necessarily influence the type of testing performed in the developmental phases of the iterative design process.

be presented with a completely new class of system, for which there are no previous techniques developed. If the logic of the development of the existing techniques described here is understood, then the tester will be able to invent the new ones as required.

The three classes of systems were chosen for several reasons. First, these are the same systems emphasized at the schools, providing a history of successful test pilot training. Next, it is possible to develop a totally unclassified discussion within the three chosen areas that is releasable in open literature. Electronic Warfare was not considered due to security issues. Computers and software were not discussed because even a basic primer on this subject would require a chapter larger than this document. Aircraft monitoring and control systems testing cannot be fully discussed without considering their effects in terms of airframe handling qualities and performance. These topics were beyond the scope of this document. In the final analysis, length precluded a discussion of even some of the remaining nine subjects and the three emphasized at the schools were selected for treatment. A fourth, Stores Management Set Testing, was added at the suggestion that the addition of a single electro-mechanical-electronic system would add depth to the document.

Since this book will only provide an introduction to the avionics test subject, it is envisioned that eventually, more advanced volumes will be written for each of the avionics categories. AGARD documents are included as references or are in work which provide partial documentation of radar, navigation and Electronic Warfare (EW) testing as well as an exhaustive series on airborne instrumentation. It is highly recommended that AGARD, or alternative organizations, champion the crafting of documents necessary to treat the balance of radar, navigation and electronic warfare testing, as well as the other areas not started. These documents would then serve as references for the active practitioner of avionics flight test.

This book emphasizes the most rudimentary form of the tests under discussion. This was done primarily to highlight the basic concepts on which the tests were designed. Typically, this implies that little or no instrumentation, test ranges or outside test assets are used in the tests which are developed. In many practical applications, more accuracy, documentation and numerical rigor are required. The reader must then refer to the more advanced flight test documents or in their absence, to experienced testers. It is noteworthy that in most cases, the basic concepts of the test do not change when more test assets are used and thus the utility of using the most rudimentary form of the tests for this introductory book.[2]

In addition to the teaching benefits, the very simple, rudimentary methods often have practical utility and should be documented. Often, these techniques are sufficient for the task at hand, when less accuracy and documentation are adequate. Money and time can thus be saved. Next, complete instrumentation also implies very complex, time consuming and expensive data reduction. There is often real pressure to constrict the time limits that test assets are available for a particular test. The rudimentary data collection can be taken concurrent with the more rigorous and the less accurate information used to adjust the next test event while data reduction occurs concurrently. The less accurate numbers can also be used to highlight problem areas and areas where requirements are easily met. This allows data reduction assets to be used where they are most needed.

Another important topic which was not documented in this book is the statistical implications of the tests, including the methods of sample size prediction, data convergence, etc. A few comments are made to highlight tests which have particularly troublesome statistical issues; however, the reader is cautioned to review any number of texts on statistics and experimental design prior to performing any rigorous testing. References 43 and 72 provide an introduction to the subject.

In order to facilitate the unclassified demonstration of the development and application of the sample test procedures, fictitious systems were chosen and placed within equally

[2]This presumption is highlighted on close comparison of the radar testing techniques outlined in this document and those presented by Scott [Ref. 50].

fictitious platforms. The specific procedures and data cards, which may include altitudes, airspeeds, target separations etc., are applicable to the sample system only and appropriate parameters must be chosen for the actual system/airframe combination under test.

In applying this document, basic knowledge in certain areas is assumed. The test planner should have a basic knowledge of avionics, although an electronics background is definitely not required. A familiarity with the operation of tactical aircraft is also important. A theory section is provided at the beginning of each of the three major sections with specific, amplifying information included in the general section of each test. The purpose of this information is to provide the reader with the knowledge necessary to comprehend the specific example system and test procedures that follow rather than a complete treatise of the entire subject. The intent is to preclude extensive outside reading to understand the test development process. When the time comes to apply the test development knowledge presented here to a real evaluation, an extensive understanding of the workings of the system under test is absolutely essential and the cursory treatment here will undoubtedly be insufficient, even if the systems are similar to the sample systems.

The layout of the individual test sections was carefully chosen with several goals in mind. Each test is fairly self-contained, exclusive of the information in the general theory sections. This allows the user of the manual to extract specific sections, reference them easily and quickly and review individual tests on the occasions where they are applicable to the system under test. In addition, the titles and contents of each section have parallels to the accepted test plan and technical report structure. Finally, the layout is similar to that used in the long accepted flying qualities and performance flight test manuals (see reference 47 for an example).

The test development process is manifested in the structure of the sections to follow. As mentioned above, the procedure is begun by exploring and fully understanding the design of the system under test. This understanding provides the insight necessary to stress the system and test it to its limits and also allows the calculation of the theoretical limits of the system. General theory applicable to each section is included in the first part of each section. Knowing the theoretical limits allows a more efficient test to be developed. This process is demonstrated later in the case study of section 7.

The choice of which parameters to test is best (and only) determined by a thorough knowledge of the workings of the system and its intended functionality. The process can be divided into two steps. First, the evaluator must define the required functionality of the system. The functional description should be defined in operational, vice engineering, terminology. This step requires a knowledge of the intended mission of the system. Secondly, the evaluator must choose the kernel of parameters which measure the performance of the required functionality defined in the first step. This task requires a thorough system knowledge. These parameters are then used as a guide for the development of the individual test procedures. The test procedures are designed to measure at least one of the critical performance parameters. The individual test procedures listed in the next three sections are titled according to the parameter under test.

The first subsection of each test procedure describes the purpose of the test, which more precisely defines the parameters under test. In the general section, the basic theory outlined in the beginning of the section is expounded upon as necessary to fully implement and understand the test procedure. The instrumentation requirements necessary to measure the parameters described in the purpose statement are then listed followed by the data required to document the parameter. Next, the procedure for performing the test is described in detail followed by a discussion of the post-test analysis of the measured data required to answer the purpose statement and the recommended format for presenting the test results. The last part of each test procedure is sample data cards used to perform the test procedure and for recording the data during actual testing.

In summary, the test design process can be described as outlined below. It may be necessary to change the order in which the tasks are performed as well as the relative importance of the tasks from test to test, but the list below will provide a guide for the general case.

(1) Research and understand the design specifications and operational use of the system under test. Use this knowledge to define the parameters critical to assessing the performance of the system and also as a means for calculating the theoretical boundaries of the system's performance.
(2) Precisely define the purpose of the test procedure to include the parameters to be measured during the test.
(3) Define the data necessary to calculate the parameter under test and assess the instrumentation requirements necessary to measure the data.
(4) Outline the detailed procedure necessary to perform the data collection effort.
(5) Define the analysis necessary to take the measured data and calculate or assess the parameter under test and then decide upon the proper presentation format to document the parameter.
(6) As a last effort, generate data cards that provide an outline of all information necessary to perform the data collection effort and record the results.[3]

2.0 AIR-TO-AIR AND AIR-TO-GROUND RADAR SYSTEMS TESTING

2.1 Introduction to Radar Theory

2.1.1 General

Radar (Radio Detection And Ranging) was first used operationally in 1937. This rudimentary system included a simple pulsed scheme to determine target bearing and range. [Ref. 9:p.1]. The first successful airborne radar was the Al Mark IV carried on the Bristol Beaufighter 19 in 1940 which used simple pulsed techniques to determine airborne target range [Ref. 56:p.2]. From these humble beginnings, radar has developed to the point that it has become the centerpiece in virtually every modern airborne weapon system. In the very simplest terms, a radar sends into space a Radio Frequency (RF) pulse of known characteristics, waits for the waves reflected off the target to return and analyzes the characteristics of the returned wave to derive information about the reflecting target [Ref. 39:p. 2.1].

2.1.2 Pulsed Radars

The simplest of radars are the pulsed radars. The operating principles of pulsed radars are based on the fact that RF energy propagates through space at a constant velocity. This velocity, strictly speaking, is applicable only in a perfect vacuum and is altered slightly by the atmosphere. Propagation velocity is a function of transmission frequency, and atmospheric molecular composition, temperature and pressure. The speed of propagation increases slightly at higher altitudes [Ref. 11:p. 81]. This effect is small; however, at the ranges and frequencies discussed in this section. For airborne test purposes, a "radar mile" of 12.36 microseconds can be defined, which is the time required for RF energy to travel out one nautical mile (nm) and then return [Ref. 27:p. 1-4.2].

The basic components of a pulsed radar include a transmitter, receiver, two antennas and a display [Ref. 60:p. 4]. Two antennas are included because the system requires a transmit antenna and receive antenna. In practice, a single antenna is time shared for both purposes. A duplexer is used to switch between the transmit and receive sides of the radar. The transmit side is connected only when actually firing a pulse and the receive side is connected to listen for returned pulses. [Ref. 56:p. 4]. This scheme prevents the transmit pulse from being directed to the receive side of the radar.

Transmitter antennas are usually designed to concentrate the transmitted pulse in as narrow a beam as possible. Similarly, receiver antennas are designed to receive signals within the same narrow beam. This phenomenon of essentially equal performance of the antenna in both transmit and receive modes is known as reciprocity and can be useful in designing tests [Ref. 36:p. 2.132].

[3] Refer to chapter 6 for a discussion of how to combine all the various tests, and their data cards, into an intelligent flight plan.

The antenna beam width is usually defined at the 3 decibel (db) power drop off points each side of the radar antenna boresight and is usually measured both horizontally and vertically [Ref. 36:p. 2.135a, Ref. 27:p. 3-1.1, Ref. 21:p. 66]. Beam width is critical since it is through this characteristic that the direction to a target is determined. As the antenna is scanning, or moved in a search pattern, the antenna pointing angle with respect to the aircraft is measured. The rate of antenna movement is insignificant when compared to the RF propagation speed. Thus the relative angle at which the radar antenna is pointing when the signal is sent out, reflected and returned, is the angle to the target. [Ref. 39:pp. 2.8-2.9]. The angle to the target is determined both horizontally and vertically. Target angle determination errors can be incurred due to the beam width of the antenna and to inaccuracies in the measurement of the antenna pointing angle. It must be noted that some modern radars can provide azimuth resolution better than the antenna beamwidth. With the exception of doppler beam sharpening, to be discussed in the air-to-ground radar section, these technologies will not be covered in this document; however, the test techniques are similar.

Antenna beam width also determines the minimum angular resolution of the radar. When two targets are at the same range from the radar, they must be separated by at least the antenna beam width to be distinguishable as two targets. Since the returned radar pulses from the two reflecting targets will arrive at the antenna face simultaneously and will thus be unresolvable without additional information (which will be discussed later). [Ref. 39:pp. 2.9-2.10]. Air-to-air radar antennas generally strive for small horizontal and vertical beam widths because this improves both the vertical and horizontal angle determination of airborne targets. Air-to-ground radar antennas use small horizontal beam widths and wide vertical beam widths, providing accurate horizontal angle determination with reasonable vertical distribution of energy over a wide range for consistent radar mapping qualities. [Ref. 56:p. 8]. An even distribution of energy over the ground allows the radar to present a more map-like display for wide ranges with fewer gaps where the radar is not illuminating [Ref. 56:p.146].

Up to this point, a very important shortcoming of all real antennas has been ignored. The effect is called sidelobing. When the desired main beam pattern is transmitted, additional patterns of similar shape but smaller amplitude are transmitted at intervals around the antenna in a three-dimensional pattern. Figure 2 shows the effect in two dimensions. All real antennas have this problem to some degree; although, the number of sidelobes and their intensity relative to the main beam vary with the quality of the antenna. The sidelobe pattern also typically changes when the antenna is installed on the airframe. Modern antennas greatly suppress the sidelobe problem with a decrease of from 20 to 100 db in the sidelobes from the main beam peak magnitude. A return from a sidelobe cannot be distinguished from a mainbeam return without special processing, and the azimuth of the sidelobe return appears to be that of the main beam return. [Ref. 56:p. 138].

A number of antenna scan patterns have been used for air-to-air and air-to-ground radars. Most modern radars use a gyroscopically or inertially stabilized, gimbal mounted antenna that allows the scan pattern to remain level with the horizon as the airplane is maneuvered [Ref. 56:p.24]. There is usually some maximum physical limit for displacement relative to the host aircraft, both horizontally and vertically. Since the antennas are normally mounted in the airplane nose, structural interference and RF interference with the airframe necessitates these limits. A limit of 60° left and right horizontally (azimuth) and 45° up and down vertically (elevation) are typical. A raster type antenna scan pattern is usually used. The raster scan moves horizontally left and right between the selected limits. Usually two or three angular widths are available for selection within the physical limits described above. Often the operator is also able to select the location of the center of the scan pattern, again within the physical limits described above. An operator would normally select a scan pattern less than the maximum limits and directed towards the target when the target bearing can be estimated. This provides more frequent scanning of the target area to reduce detection time. For air-to-air applications, the horizontal path is usually stepped up and then down by an incremental angular amount. Each horizontal scan is known as a bar and may be selected in number [Ref. 56:p.5], usually from one to four. Each bar typically overlaps slightly.

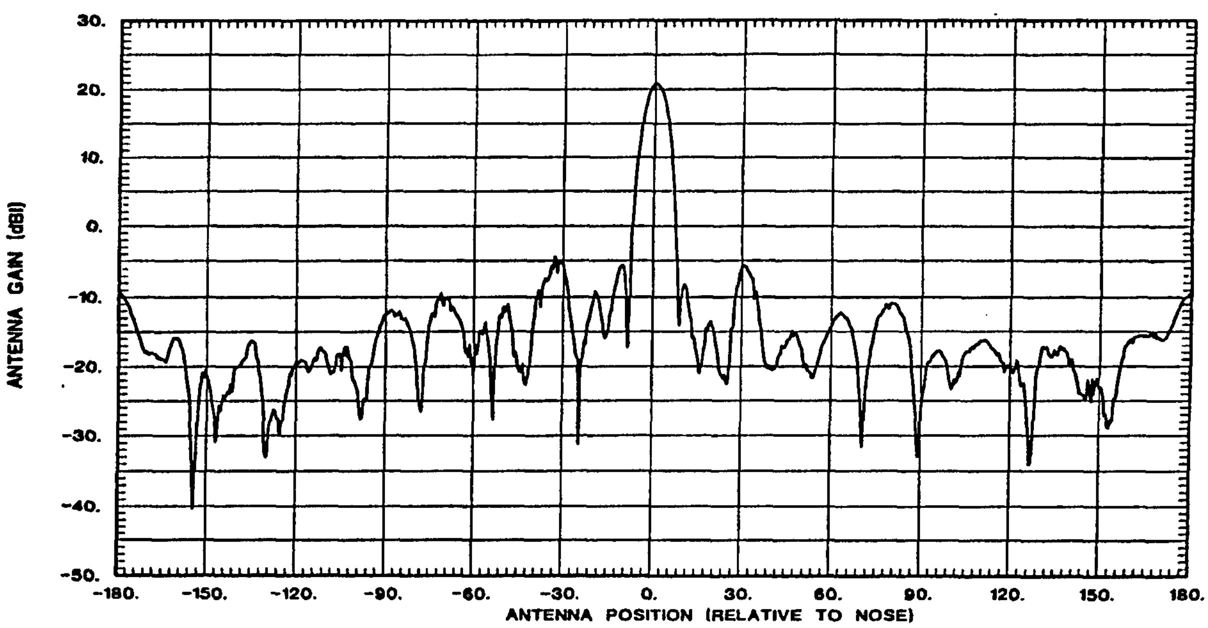


Figure 2: Two Dimensional Antenna Sidelobe Pattern

As the number of bars and the scan azimuth width are increased, the search volume increases and consequently the time between target illuminations increases. Increasing antenna scan rate can be used to counter this problem somewhat; however, if the scan rate is increased, the amount of time the target is within the antenna beam width, and thus the number of pulses illuminating the target per scan, is decreased. A tradeoff is necessary to optimize the number of hits per scan and to minimize the time between scans over the target. Usually the search volume is limited to that which can be supported by the radar and still be tactically useful. A multiple bar scan pattern is necessary to cover the search volume because a narrow vertical beam width is needed to allow altitude of the airborne targets to be determined. Knowing the vertical angle to the target (calculated in the same manner as the horizontal angle to the target) and the target range, a simple geometric calculation provides the target altitude relative to the host aircraft. This can be added to the host aircraft altitude to determine the target altitude.

Air-to-ground radars normally operate with a single bar scan pattern, and therefore the scan rate and scan angular width determine the refresh rate of the display. The number of hits per scan is maximized to maintain a consistent, map-like display and so the tradeoff is one of providing a quick scan rate to shorten the refresh period and a long one to keep the number of pulses over a given azimuth high enough to provide a consistent, map-like display.

The ideal, pulsed radar sends out the RF energy in discrete packages (pulses) of a specified duration. The pulse duration ideally has very rapid rise and fall times. It is assumed here that the rise and fall times are essentially instantaneous since modern radars come very close to achieving this goal. The pulse width defines both the theoretical minimum range and the theoretical minimum range resolution. The theoretical minimum range is defined in the following equation [Ref. 39:P. 2.7B]:

$$R_{min}=\frac{(C)(PW)}{2}$$
$$C\text{=The speed of light or } 3 \ X \ 10^{8} \ \frac{meters}{second}$$
$$9.7125 \ X \ 10^{8} \ \frac{feet}{second} \qquad (1)$$
$$161{,}875 \ \frac{nm}{second}$$
$$R_{min}\text{=theoretical minimum range}$$
$$PW\text{=Pulse Width}$$

Any target closer than this range will not be observed since the duplexer will still be switched to the transmit side of the radar. The theoretical range resolution limit ($R_{min\ res}$ or minimum range resolution) is equal to the same value. [Ref. 39:p. 2.8a]. Since the return from the farther of two targets, that are closer together than the range resolution limit, will be received at the receiver coincident with that of the nearer target and will thus be unresolvable without additional information (discussed later). From these considerations a short pulse width is desirable; however, a long pulse width is needed because energy is transmitted only during the duration of the pulse and the average power illuminating the target increases as the pulse width is increased. This increases the probability of detection, all else being equal. [Ref. 56:pp. 159-160].

The number of times that the pulsed radar transmits its pulse per second is known as the Pulse Repetition Frequency (PRF). PRF determines the maximum theoretical unambiguous range. The radar waits between transmissions for return pulses. If the PRF is too high, and thus the time between pulses is too short, the return from a previous pulse will return while the radar is waiting for the return from a more recent pulse. The time interval between pulses is called the Pulse Repetition Interval (PRI). The radar would be unable to determine which transmitted pulse the returns were associated with, and some returns would be associated with the incorrect time slot. [Ref. 56:pp.157-158]. Conversely, the PRF must be kept as high as possible to increase the average power out of the radar and thus the probability of detection. There are methods for resolving ambiguities between interpulse periods. The simplest is merely to vary the transmitted RF frequency from pulse to pulse, correlating a return pulse with its associated transmitted pulse by matching frequencies. [Ref. 39:p. 2.8]. For a simple pulsed radar without special techniques applied, the theoretical unambiguous maximum range is defined as [Ref. 39:p. 2.8b]:

$$R_{max\ unamb}=\frac{(C)(PRI)}{2}$$
$$R_{max\ unamb}\text{=theoretical unambiguous maximum range} \qquad (2)$$
$$PRI=\frac{1}{PRF}$$

Frequency can affect the maximum range of the radar since some frequencies are impacted by molecules and particles within the atmosphere more than others. The impact is a function of the wavelength of the radar RF frequency relative to the diameter of the various particles and molecules in the atmosphere. The effect can be dramatic. Wavelength is related to frequency by the following expression [Ref. 56:p. 125, Ref. 27:pp. 5-1.1-5-1.3]:

$$C=f\lambda$$
$$C\text{=speed of light} \qquad (3)$$
$$f\text{=frequency in hertz}$$
$$\lambda\text{=Wavelength in meters, feet, etc. as appropriate}$$

Some frequencies propagate through the atmosphere with less absorption than others. At the frequencies most used for air-to-air and air-to-ground radars, oxygen and water molecules are the greatest absorbers of RF energy [Ref. 56:p. 125, Ref. 27:pp. 5-1.1-5-1.3]. Lower frequencies can actually propagate beyond the horizon by bouncing downward in the upper atmosphere, bouncing up from the ground and/or by conforming somewhat to the curvature of the earth [Ref. 36:p. 2.80]. Air-to-air and ai to-ground radars are generally w above this frequency since the lo frequencies require large antennas (most antennas are optimized at multiples of 1/2 the RF wavelength). Virtually all the radars that fall in the categories discussed here radiate at between 6 GigaHertz (GHZ) and 18 GHZ. At these frequencies moisture content of the atmosphere has an effect because of the wavelength relative to the water molecule's size. Also, these frequencies propagate essentially on a straight line path, that is, along the line of sight. [Ref. 36:p. 2.80]. Above the 20 GHZ level, the atmosphere absorbs virtually all the RF energy at short ranges [Ref. 36:p. 125].

The tools have now been presented to analyze one of the most crucial features to be evaluated on a new radar. This parameter is the maximum detection range of the radar (not the same as the maximum unambiguous range). This characteristic receives much attention during a test program because it is often the performance feature by which radars are compared and measured. Reference 36 provides a good derivation of the radar range equation which is presented here without proof [Ref. 39:pp. 2.12-2.15]:

$$R_{max}=\left[\frac{PG\sigma A}{(4\pi)^2 L\ k\ T\ B_n F_n\left(\frac{S}{N}\right)_{min}}\right]^{\frac{1}{4}} \quad (4)$$

P=Transmitted power of the radar.

G=Directive gain of the antenna, a measure of the ability of the antenna to direct the RF along a straight line rather than transmit it evenly around the antenna in a spherical pattern (isotropically).

σ=The radar cross section of the target. "The radar cross section of a target is that area which, when multiplied by the radar signal power density incident upon the target, if radiated isotropically by the target, would result in a return back at the radar equal to that of the actual target" [Ref. 39:p. 2.16]. Simply, the radar cross section is a measure of the ability of the target to reflect radar energy. The radar cross section varies with the specific frequency, and thus wavelength, and changes, sometimes dramatically, as the angle of incidence upon the target changes [Ref. 39:p. 2.17, Ref. 28, Ref. 8, Ref. 44:pp. 89-127].[4]

A=The radar antenna capture area.

L=A loss factor which accounts for non-specific losses within the radar receiver.

$(k)(T)(B_n)(F_n)$=All are related to the interference within the system caused by thermal noise. Thermal noise is a function of the absolute temperature of the system and the band width of the system. Most modern radars have come close to optimizing this set of parameters; and, as such, there is little room for improvement for the designer.

$(S/N)_{min}$=The Signal to Noise ratio is a measure of the signal strength divided by the noise received. The minimum signal to noise is that S/N that can just barely be identified as an actual target. The $(S/N)_{min}$ depends on many factors, most of which can only be defined poorly. Operator experience and the accepted false alarm rate are examples of these variables.[Ref. 14:p. 2.15]. Modern radars can have an $(S/N)_{min}$ well below unity using advanced processing techniques to pull the target's returned energy out of the noise level. Some will be discussed later.

Note that the entire expression is raised to the 1/4 power. Improving any one factor by 16 will only double the radar range. [Ref. 39:p. 2.15]. σ is a function of the target and not under the control of the radar designer. $(k)(T)(B_n)(F_n)$ are only slightly under the control of the designer since some thermal noise must exist in any real system and most modern systems handle this problem fairly well. L is very close to unity in many modern systems and; therefore, cannot affect the order of magnitude changes necessary to significantly increase the radar range. A is limited by the frontal cross sectional area of the airplane nosecone which is where most radar antennas are housed. [Ref. 56:p. 127]. This leaves P,G and $(S/N)_{min}$ for the designer to manipulate and affect maximum range.

Peak power out is usually limited by the physical weight and size of transmitters that have to be carried in airplanes. Lowering peak power reduces airplane weight. [Ref. 56: p.124]. A pulsing scheme has to be worked out to lower peak power while optimizing average power over time [Ref. 56:p. 159-160]. Generally, some modulation scheme of either frequency or PRF is used to allow increasing the pulse width or PRF to effect greater average power while at the same time not sacrificing other radar parametric performance. Some of these techniques are described later. Increasing average power can cause other problems. As power output is increased, the probability of the signal being received by the enemy and exploited is

[4]Knott, Shaeffer and Tuley, reference 28, is the best volume on radar cross section I have read to date. It also includes a truly outstanding discussion of radar cross section reduction techniques. This is a must reference for all concerned with testing modern air-to-air or air-to-ground radar systems.

increased [Ref. 39:p. 2.12-2.13]. Since the signal path to the enemy receiver is only a one way path, the radar range equation dramatically shows the importance of keeping the power levels within limits. One technique makes use of the ambient noise level to hide the transmitted RF.

Antenna Gain is improving at a slow but steady rate. Most modern radars rely on slotted array planar antennas which are a pattern of slot shaped antennas aligned in a flat plane. These planar arrays achieve a G of as much as 40 db in current production systems. The minimum signal to noise ratio can be improved by increasing the sensitivity of the receiver while at the same time improving the capability to reject ambient noise. Rejecting noise keeps the false alarm rate down. Many techniques involve modulating the transmitted signal in a unique fashion not duplicated in nature to allow the receiver to differentiate between the return signal and noise. The power density can be spread out to a lower level than the ambient noise and then pulled back out at the receiver. This is possible because a pseudo-random code known only by the transmitting radar is used to modulate the RF. The code must be known to pull the signal out of the noise. The signal is almost impossible to detect without the code since the pseudo-random modulation makes it look like noise. This technique is finding application in a large number of current and developing communication and radar systems. [Ref. 36:pp. 2.108-2.111].

2.1.3. Doppler Radars

The operating principles of doppler radars are based upon the fact that RF reflections from a target that is closing in range radially along the direction of propagation are shifted up in frequency, and reflections from a target that is opening in range are shifted down in frequency. This phenomenon is demonstrated in the audio spectrum by a train passing with the horn sounding. The horn sounds higher in frequency as it is approaching and then lower in frequency as it is receding. [Ref. 56:p. 9, Ref. 27:pp. 2-2.1-2-2.5]. It must be emphasized that this measurement is limited to radial velocities only [Ref. 56:p. 9, Ref. 27:pp. 2-2.1-2-2.5]. A target could be moving hypersonically, perpendicular to a non-moving doppler radar, and it will exhibit a zero doppler shift. Another point to note is that a doppler shift is also imparted by ownship motion. For example, ground clutter directly along the flight path of the airplane will tend to exhibit a doppler shift equal to the groundspeed of the airplane [Ref. 13:p.2.36, Ref. 27:pp. 2-2.1-2-2.5]. Several techniques are available for eliminating doppler shift due to ownship motion. The simplest technique is merely to filter out all doppler shifts around the ownship groundspeed motion induced doppler value along the radar boresight [Ref. 56:p.9]. This technique is often used in air-to-air radars.

A number of techniques have been devised for detecting targets that are moving with respect to ground clutter. These systems are known collectively as Moving Target Indicators [Ref. 39:p.2.48] or in the case of airborne radars as Airborne Moving Target Indicators (AMTI) [Ref. 39:p.2.29]. One class of AMTI radars uses only the doppler effect to detect moving targets. These radars use very long pulses to increase the average power and consequently cannot determine range to the target. In this situation, the only reason pulsing is used is to allow the same antenna to be employed to transmit and to receive. Target bearing is found as in pulsed radars. The high average power and sensitivity to closure rate make these radars ideal for gaining relatively long range detection on high closure rate targets. The high average power output improves small σ target detection (the increase in P compensates for a small σ in the radar range equation). The rejection of ground clutter based upon the ownship motion doppler shift filtering described above also increases the probability of small target detection in the clutter. All these effects make the doppler mode of operation ideal for the detection of small, low flying cruise missiles closing on the radar.

Several doppler radar parameters affect the performance of the system. One parameter is the accuracy with which the doppler shift (frequency change between the transmit and receive signal) can be measured. This accuracy directly relates to the ability of the radar to discern between two targets close together in bearing and also close together in closure speeds. As the difference in doppler shift approaches a value equal to the doppler shift accuracy, the targets become unresolvable in closure speed. The uncertainty in doppler frequency shift is directly convertible to a closure rate uncertainty. [Ref. 39:p.3.18].

2.1.4. Pulse Doppler Radars

Pulse doppler radars combine the ranging capabilities of the pure pulsed radar with the closure velocity determination capability of the doppler radar. With this technique, doppler shift measurements are applied within the pulse width of the transmit and reply signal providing the best of both radars, although not without added complications. All of the performance limitations of both pulsed radars and doppler radars apply; however, the pulsing of the doppler RF adds several new limitations. The first is caused by the effects of frequency folding or aliasing. [Ref. 39:p. 2.34].

The pulsed radar is essentially a data sampling system and, as in any sampling system, "the sampling process creates new frequencies, other than the desired transmit frequency, which replicates the desired spectrum in the frequency domain, at intervals equal to the sampling rate" [Ref. 39:p. 2.34]. The sampling rate is equal to the PRF for radar applications [Ref. 39:p. 2.34]. The return signal replicates itself at a lower power level, at multiples of the radar PRF [Ref. 39:p. 2.34b]. As described, this effect occurs for a simple sinusoidal signal and becomes even more complicated if the signal is further modulated as are most radar signals. Since the doppler portion of the pulse doppler radar measures the frequency change of the transmitted RF, this problem is serious and results in ambiguous doppler shifts, and thus ambiguous radial velocities, at each frequency fold. [Ref. 39:p. 2.35]. The solution to the problem is to select a PRF high enough such that the first frequency fold occurs at a doppler shift, and thus a closure speed, higher than of interest to the operator. In a pulse doppler system this is contrary to the requirement of having a low PRF to prevent range ambiguities. A tradeoff occurs in these radars between low/high PRF and thus range ambiguities/closure rate ambiguities. The best solution depends upon the intended use of the radar. [Ref. 39:p. 2.42].

Another problem results from the effects of ground clutter returns on various portions of the radar transmission pattern. Since all real radar antennas have antenna patterns with sidelobes outside the main radar beam, ground clutter returns are of three different types. The highest amplitude return is caused by the main beam itself and is due to the doppler shift from ownship motion along the radar line of sight. Along with this return is a return which is much wider in its frequency spectrum and lower in power caused by clutter in the radar sidelobes. Finally, a narrow frequency spike occurs at the transmit frequency due to the return from the ground immediately below the aircraft. This is called the altitude return. The entire spectrum is illustrated in figure 3 [Ref. 39:pp. 2.35b-2.36].

Without further processing, the target return would have to be strong enough to break out of the clutter and noise combination. It is very unlikely that a small target would be seen within any of the clutter pedestals described. A common method of handling this problem is simply to filter out all of the main beam, altitude return and sidelobe clutter pedestals, requiring the target to only break out of the noise [Ref. 39:p. 2.37]. Unfortunately, this eliminates a wide spectrum of closure rates where the target would not be seen, but leaves few false alarms. Other radars leave the sidelobe clutter pedestal. The effect is fewer excluded closure rates but a lot of noise in the sidelobe clutter pedestal for the radar and/or the operator to sift through. The target return must be strong enough to be seen inside the pedestal [Ref. 39:p. 2.37] and the false alarm rate is usually increased. Fortunately, other methods have been devised for dealing with clutter. One will be discussed here as an example. Delay Line Cancelers (DLCs) allow the radar to save the return pulse from one PRI to another and then to pass the two through a filter. The two are essentially subtracted from each other and the difference is due to changes over time, that is, motion over the ground clutter.

When using the simple method of subtracting out the clutter pedestals, there are resultant blind speeds, around the speed of ownship, along the radar line of sight. This problem is complicated when frequency folding occurs since this leaves one blind closure rate for each fold. When using DLCs, there is a minimum speed over the ground clutter that the target must make for the DLC circuitry to be able to discern a minimum resolvable change from pulse to pulse. This means there is also a minimum resolvable closure rate. DLCs are also susceptible to frequency folding just as in other pulse doppler systems and thus these minimum doppler shift closure rates may be repeated at

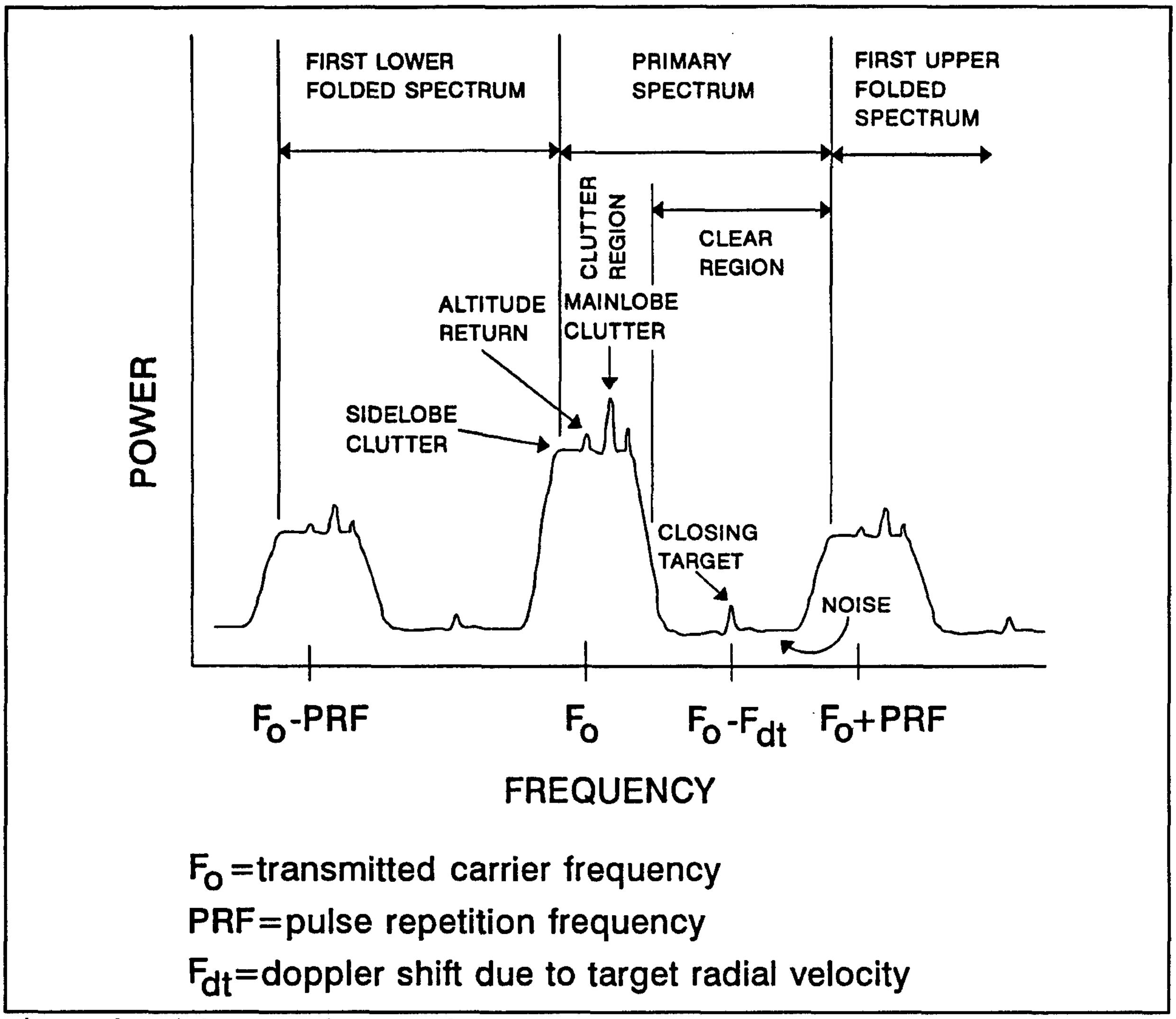


Figure 3: Airborne Pulse Doppler Return Spectrum

intervals over the velocity spectrum. [Ref. 56:pp. 425-426].

2.1.5. Advanced Techniques

2.1.5.1. Pulse Compression

The first advanced technique to be discussed is pulse compression. In pulse compression, the transmit pulse is generated with a spread of frequencies within a defined band. The pulse is then passed through a filter, called a Dispersive Delay Line (DDL). The effect of the DDL is to arrange the RF within the pulse such that the lower frequencies are transmitted at the beginning of the pulse width, linearly increasing to the higher frequencies by the end of the pulse width. The return pulse is then passed through the same filter in the opposite direction, which slows the lower frequencies in the lead and by the end of the pulse applies no delay. The effect is to stack the return pulse. The result is to provide better range resolution from the narrow processed pulse width with the benefits of high average power from the wide transmit pulse. Typical compression ratios are around 100/1. [Ref. 56: pp. 217-218]:

$$compression\ ratio = \frac{transmitted\ PW}{compressed\ PW} \qquad (5)$$

$$PW = pulse\ width$$

2.1.5.2. Doppler Beam Sharpening

The next technique to be discussed is Doppler Beam Sharpening (DBS). DBS has found application mostly in air-to-ground radars. As the radar antenna is scanning, the antenna boresight moves from side to side. The ground target doppler shift is a measure of the component of the host airplane's velocity along this boresight. All fixed ground targets have a doppler shift caused by the geometric component of own aircraft motion along this boresight. For these reasons, as the antenna scans, the ground return doppler shift will change by a predictable amount. DBS makes use of this concept by measuring the doppler shift of the ground returns and comparing them to the doppler returns for adjacent returns in azimuth to determine very precise angles off of the aircraft ground track. The result is a very precise angular determination for target returns, much better than the antenna beam width. Unfortunately, the doppler shifts vary slightly from pulse to pulse around the theoretical value and the information must be integrated over time to get the true value. A lot of radar information must be stored to display the entire search volume and the display often requires 10 to 15 seconds to build. The data is normally stored in small angular and range bins within the radar computer and the display usually appears like small building blocks of varying intensity. A lot of computer memory and processing time is required for this process.

Since DBS only affects angular resolution, some technique is needed to improve range resolution consistent with the angular improvement. This is usually accomplished merely by decreasing the pulse width of the transmit signal enough to provide a harmonious balance of angular and range resolution. The reduced pulse width also reduces average power and in turn reduces the maximum DBS range to 40 or 50 nm. Another limitation of DBS is caused by the geometry of the technique. The doppler shift change close to the radar ground track is very small as the radar sweeps, increasing by the cosine of the angle off of the ground track to a maximum as the perpendicular position is reached. A minimum discernable change is required to be resolvable, causing a small notch, usually 7° to 15° wide, over the nose of the airplane, where the DBS picture is blanked. In some radars, this is filled, with limited success, with real beam radar video. Most state of the art DBS radars can provide a map like display with an order of magnitude improvement in resolution within the constraints discussed above. [Ref. 56:pp. 2.66-3.29].

2.1.5.3. FM Ranging

As discussed above, the more continuous the transmission pattern, the higher the average power out and the longer the maximum detection range. The drawback of extremely long pulse widths is that ranging of the target becomes impossible. Frequency Modulation (FM) ranging provides ranging data even with very long or continuous pulse trains. In FM ranging, the pulse train is ramped linearly up in frequency to a peak from some baseline frequency and then linearly ramped down to the original baseline. This pattern is repeated at intervals roughly equivalent to conventional pulse repetition intervals. The return pulse is then compared to the transmitted pulse to find the peak, providing a time reference from which to determine the time of propagation to the target and back. Instead of measuring the time from transmission to receipt of a discrete pulse, the time from transmit to receipt of the peak is measured, providing range. [Ref. 39:pp. 2.29-2.32]. In practice, this technique is much less accurate (by as much as an order of magnitude) than pulse ranging and has poor resolution, but reasonable ranges can be determined for the long range targets that the wide pulse width radars are designed to detect. The reduced range resolution and accuracy are a result of the inherent inaccuracies associated with determining the precise point of the frequency peak. [Ref. 56:pp. 239-240].

2.1.6. Displays

Two types of display formats have found application in most modern air-to-air and air-to-ground radars. The most widely used, and most versatile, is the Plan Position Indicator (PPI) format. In this format, the sweep emanates from a single point, usually the bottom center of the scope, and describes a slice of a circle with radius equal to the sweep length. The origin of the sweep is the ownship position and the target's position relative to ownship is measured as the bearing of the sweep and range from ownship. [Ref. 56:p. 25, Ref. 27:pp. 5-5.3-5-5.6]. Since a pure bearing/range format from ownship is used, the display closely resembles the real world. That is, if a mapping mode is being used, the radar display will resemble the real world. The bearing and range measurements are made as direct line of sight measurements and as such do involve some slant range errors. These errors account for slight distortions at short ranges. Another short range distortion is caused by the very shape of the display. Since the display comes to a notch near ownship, targets near the notch of the V are very cluttered, and as such, resolution generally suffers very close into ownship. Both of these short range display problems can affect the minimum usable range of the radar and can cause it to be greater than the theoretical value described earlier.

Some applications require a quick and accurate representation of target bearing and range more than the map like picture described above. One application is in fighters, where accurate target angle and range information is required to set up and execute intercepts. For these purposes, the B scan format display has found application. B scan displays are set up with range on the y axis and angle to the target on the x axis [Ref. 56:p. 25, Ref. 27:pp. 5-5.3-5-5.6]. This format is more a display of information rather than a picture of the real world. The effect is to "spread the world out" at short ranges, distorting the picture. The B scan has limited application in the air-to-ground arena, although some applications exist. Air-to-ground B scan applications are usually limited to small area displays offset from ownship (patch map) [Ref. 56:p. 25]. DBS often uses a B-scan format to facilitate conversion from memory storage in the range and azimuth bins to display. Velocity Search (VS) modes are displayed with angle to the target on the x axis and closure rate on the y axis [Ref. 39:p. 3.26]. Figure 4 includes samples of several display formats.

Display resolution is important in all display formats. Often the display has less resolution than does the radar system. As a result, a lot of good radar system design work suffers. Cathode Ray Tubes (CRTs) are used in most displays today. These displays have a fairly well defined resolution based upon the number of raster lines per inch, or the number of resolvable points per inch that are displayable. This number is applicable to both dimensions on the display. Knowing the selected range scale, the theoretical resolution limit can be determined.

$$\textit{display resolution} = \frac{(\textit{scale in nm/in})}{(\textit{raster lines per display inch})} \qquad (6)$$

For the digitally driven CRT digital displays in use today, the presence or absence of a target is usually easily interpreted by the operator. For the old analog displays still in use, display quality, system set up and operator proficiency can greatly affect nearly every radar parameter.

2.1.7. Analog Versus Digital Displays

Almost all new radar system displays are implemented in a digital format. This means that analog to digital conversion of the radar return takes place and some amount of radar processing is used before the information is displayed to the operator. The benefit is a cleaner display gleaned from the chaos of the analog world with only the necessary information making it to the display. Decreasing the unusable information from the display tends to reduce operator workload. This is perhaps the major advantage of the digital format. The displays are clean and target presence is easy to determine. The major disadvantage of the digital format is that in paring out the clutter, the system often deletes usable information. Analog displays leave everything for the operator to interpret himself. For this reason, a skilled operator with time to concentrate on the analog display can almost always out perform a digital system. The disadvantage of analog is the time and concentration required, which distracts the operator from making tactical decisions.[Ref. 27:pp. 5-5.1-5-5.2]

2.1.8. Radar Tracking

Two types of air-to-air radar tracking modes are common to modern radars. The first, Single Target Tracking (STT), is implemented by concentrating the radar on a single, selectable target and using the output to determine target parameters. For a ranging mode, this includes the target's range, bearing, course, groundspeed and altitude. The antenna is typically pointed at the target and a feedback process is used to determine the target parameters. For a VS mode, the target's bearing and closure rate are tracked. [Ref. 39:p. 2.55]. The advantage of an STT mode is that the course and groundspeed can be determined for a pulsed mode and also the radar is concentrated on a single target, increasing the detection level. STT is typically selected when a target is chosen for intercept and intercept

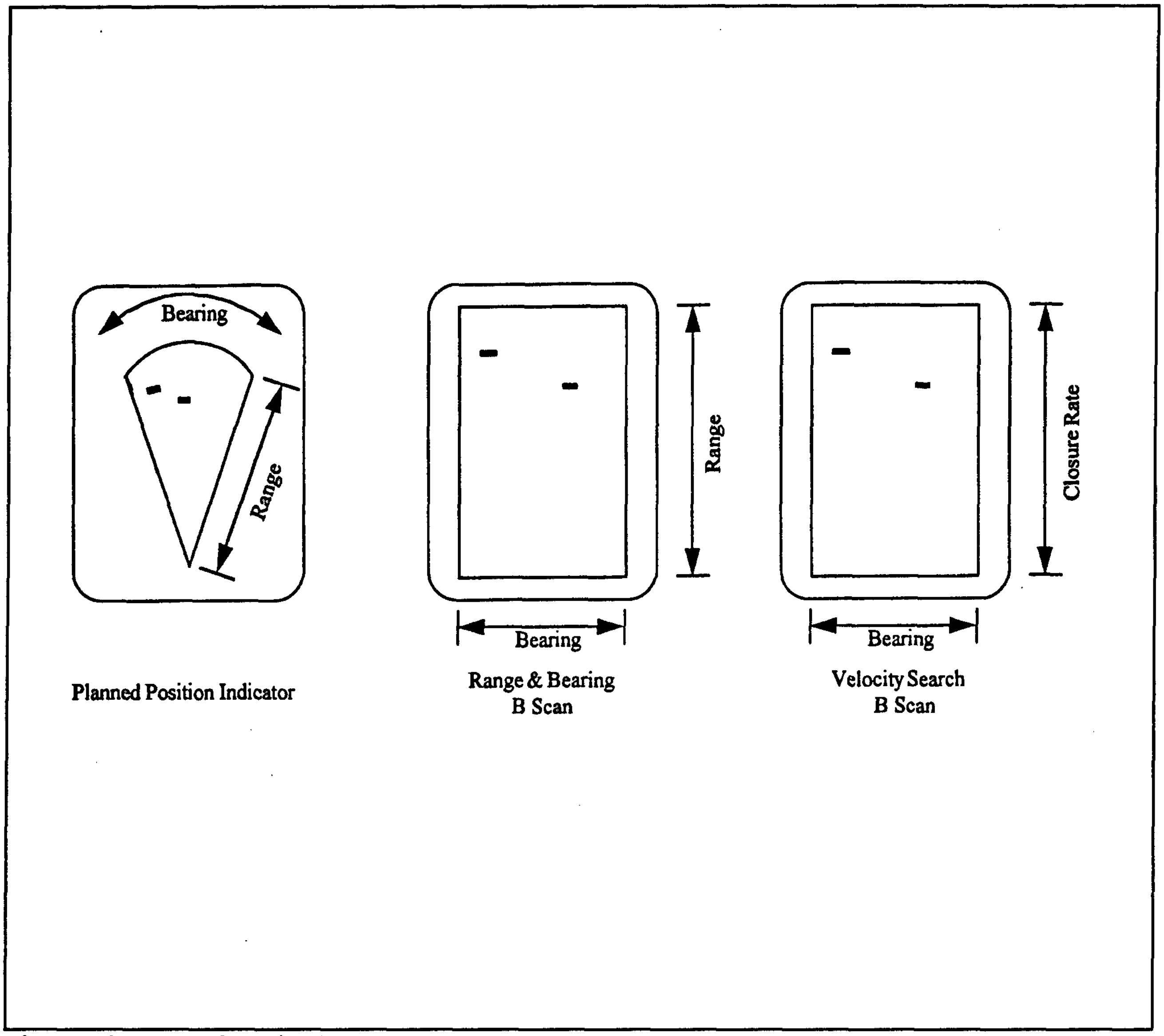


Figure 4: Sample Display Formats

calculations and display formats are usually provided.

The second air-to-air tracking mode, Track While Scan (TWS), allows the radar to continue to detect targets within the search volume while determining track parameters (course, speed and altitude) on some number of tracks within the same search volume. The antenna continues to scan and the radar saves the detected target parameters from each scan, using the information to determine a bearing, range, course, groundspeed and altitude on the targets. The advantages of TWS are increased Situational Awareness (SA) outside of the area of the target being intercepted, while still calculating target course, groundspeed and altitude. The disadvantage of TWS is that the detection level for individual targets is reduced from the STT level. [Ref. 39:pp. 2.61-2.62]. The number of possible track files varies with the individual radar.

For air-to-ground radars, geographically stable cursors for designation of ground targets are common. The cursors, which may take the form of cross-hairs or brackets on the display are placed over the target by the operator. The position of the cursors are stabilized geographically by the navigation system of the airplane [Ref. 39:p. 3.27]. The cursors stay stationary relative to the radar video. Unwanted motion in the cursor is a result of navigational drift, causing the cursors to move relative to the radar video. The cursors are used for designating a target position for use by the fire control computer, for navigation updates, etc.

2.1.9. Missions

A radar is designed for a specific mission and testing procedures have to be tailored and the results analyzed to reflect emphasis on the parameters important to the mission. For military radars, these missions are often explained in a general way in the individual aircraft detailed specifications, Test and Evaluation Master Plans (TEMPs), etc. These documents tend to be vague. For this reason, when designing tests and in analyzing the results, it is essential that the evaluator have an in depth knowledge of the intended use and expected environment. Operational experience in a similar platform is not essential but extremely helpful. If this experience is not available on the test team, extensive research is called for. As an example, the choice of targets for air-to-air testing should always reflect the intended threat. An interceptor designed to defend against large, long range, strategic bombers would require a different target than a fighter designed to defend an attack group against other small, agile fighters. The target should reflect the intended use and in fact many new detailed specifications are written with this in mind, in that the detection/tracking sections are written in terms of targets that are similar in radar cross section and performance to the threat. Many other examples are possible. The concept is often called "mission relation" and is applied to the test design, data analysis and in the justification of the final results.

Mission relatable tests are particularly important in the test techniques presented here. Since these techniques are designed to provide a quick/inexpensive assessment vice an in-depth engineering analysis, there is not much time to completely cover a plethora of data points. The important data points have to be acquired in a mission relatable scenario and the analysis has to reflect this mission relation. As an example, when doing maximum detection range tests, the designing engineer would desire an in-depth set of detection data over a wide variation of environmental conditions (i.e.: low/high clutter, visible moisture/clear weather, wide closure speed range, etc.) From an engineering standpoint, this allows the engineer to be able to see the effects of extremes of the possible variables; however, it may tell little about how the radar will perform in its intended environment. This is the goal of the techniques presented here. Money and time can often limit the number of data points per test to one or two. A mission relatable target in a scenario that reflects the intended use of the radar is required. The evaluator must understand the mission before designing the test, and must test to the mission.

2.1.10. Radar Systems Human Factors

No attempt will be made here to completely cover the topic of human factors; however, the introduction of a few concepts specifically applied to airborne radar is in order. First, anthropometric data and the concept of the Design Eye Position (DEP) must be discussed.

In 1964 a study of 1,549 Naval Aviators was performed to obtain 96 body measurements [Ref. 66]. Items such as weight, height, height from the seat to the eyeball position, reach length, etc., were collected for a wide group of aviators and then statistically analyzed. The outcome of the study was a definition for each parameter of the average measurement and measurements below which various percentages of the group would fall. Most aircraft specifications are written to require the 3 to 98 percentile group (measurements that are at least as great as the lowest 3 percent and lower than the upper 2 percent) to be able to manipulate and use all the furnishings, controls and displays in the cockpit [Ref. 47:pp. XV3-XV4]. As an example, most cockpit seats are designed to be adjustable up and down over a certain range. The center of this range is almost always optimized to accommodate the average, or 50 percentile individual, described above, and the upper and lower limits are almost always designed to accommodate the 3 and 98 percentile persons.

There is an eye position within the cockpit for which all the cockpit controls and displays are optimized. The range of seat adjustments described above are designed to allow placing the eye of the 3 to 98 percentile persons at this position. This is called the Design Eye Position (DEP). [Ref. 47:pp. XV4-XV5]. This is the point from which all control and display tests should be performed. The DEP is usually close to the midway seat position for the 50 percentile person. The correct seat position to place the evaluator's eye at the DEP can be approximated by placing the seat at the center of the range of adjustment and finding the evaluator's anthropometric sitting eye height and the 50 percentile sitting eye height from the anthropometric data tables. The two can then be subtracted and for the taller person the seat can be moved down by the difference to drop the evaluator's eye to the correct position. For the shorter person the seat is raised by the difference. While wearing a standard flight helmet, the head is placed against the head rest. The evaluator's reach is defined while the head is placed at this point.

Controls and displays should be evaluated while seated at the DEP and wearing normal flight clothing. A complete set of anthropometric data should be collected on each evaluator and the measurements documented in all reported test results. A deficiency with control reach is meaningless when the cockpit was designed for a reach range that does not include the evaluator. The clothing and personal flight equipment worn should also be documented.

A good discussion of the specifics of human factors standards applied to radar displays and controls can be found in references 13 and 14.

2.1.11. The Sample Radar System

The sample radar used to illustrate the development of the basic radar test techniques is a multimode air-to-air and air-to-ground radar installed on a modern fighter/attack airplane. The air-to-ground radar modes include real beam map as well as DBS modes. Geostable cursors with digital displays are available. The air-to-air radar modes include pulse compressed, VS and FM ranging. The radar will operate in either search or TWS air-to-air modes.

2.2. AIR-TO-AIR AND AIR-TO-GROUND RADAR TEST TECHNIQUES

2.2.1. Preflight and Built-in-Tests

2.2.1.1. Purpose

The purpose of this test is to assess the suitability of the radar preflight and turn on procedure and the Built-In-Test (BIT) to quickly and easily bring the radar on line and insure an operational or "up" system, once airborne.

2.2.1.2. General

As airplanes become more expensive, fewer and fewer will be available to accomplish each mission, amplifying the loss of individual airplanes to inflight failures. Quick, accurate ground preflight tests are essential to determine system status while repairs can still be performed. A quick response/alert time is also important and so these checks must be expeditious and must allow the operator to prepare for the mission with a minimum of distractions. Limited airplane availability also implies the need for quick turn-arounds to send the same aircraft out for successive missions. This necessitates a very short preflight and turn on procedure that can be accomplished safely and thoroughly before a hurried combat mission.

2.2.1.3. Instrumentation

A stop watch and data cards are required for this test. A voice tape recorder is optional.

2.2.1.4. Data Required

Qualitative comments, time to complete the preflight/turn on and time to complete the BIT is required. A record of BIT indications are required.

2.2.1.5. Procedure

Perform a normal system turn on before each test flight using the published system check list. Note the times for radar time out and the total system preflight time up to the ready for operate indications. Perform a preflight BIT, noting the total BIT time and indications. Note any correlation between the BIT indications and the radar's operation. Perform a complete system check out of the failure indications. Make qualitative comments as appropriate.

2.2.1.6. Data Analysis and Presentation

The time and complexity of the preflight procedures listed in the operator's checklist and radar turn on/timeout procedure should be related to the expected alert launch time requirements and the overall operator workload during the alert launch. The BIT times and the amount of operator interface required to perform the BIT should be assessed in the same scenario. Clarity of the BIT indications should be related to the cockpit environment. The BIT indications should be related to actual radar degradation and verified by ground technicians. Erroneous BIT false alarms should be noted and related to the probability of unnecessarily missed sorties.

2.2.1.7. Data Cards

Sample data cards are presented as cards 1 and 2.

CARD NUMBER ____

PREFLIGHT/TURN ON

CLARITY OF CHECKLIST INSTRUCTIONS:

LOGICAL SEQUENCE OF CHECKLIST:

THOROUGHNESS OF CHECKLIST:

SYSTEM STATUS/RADAR TIMEOUT COMPLETE INDICATIONS:

RADAR TIMEOUT TIME____________________

TOTAL PREFLIGHT TIME INCLUDING TIMEOUT________________

Card 1: Preflight/Turn On Data Card

CARD NUMBER ____

BUILT IN TESTS

INITIATION PROCEDURES:

RUN/FINISH INDICATIONS:

BIT FAILURES AND QUALITATIVE FUNCTIONAL ASSESSMENT OF RADAR/RESULTS OF GROUND MAINTENANCE CHECKS:

Card 2: Built In Tests Data Card

2.2.2. Controls and Displays

2.2.2.1. Purpose

The purpose of this test is to assess the suitability and utility of the radar controls and displays for the assigned mission as an interface between the operator and the radar system.

2.2.2.2. General[5]

As good as many radars are in determining the parameters of the target, they have failed if the operator is not presented with a usable display or if the operator is not given adequate controls to operate the system. The controls and displays must be usable in every conceivable flight regime, ambient lighting condition, weather condition, and by aviators with the range of anthropometric measurements for which the system was designed to operate. For the modern fighter or attack airplane this is usually all weather, day or night, around +9 to -4 g's, for the 3 to 98 percentile groups, and in a realistic tactical environment filled with urgent decisions demanding the aviator's attention. For this reason, the controls and display should require an absolute minimum of operator input or interpretation and the information imparted and required from the operator should be a minimum and precisely what the aviator needs to execute the current phase of flight.

Controls should be easily manipulated wearing the proper flight clothing. The range of control (both the physical range of movement of the knob, dial, lever, etc. and the range of effect that the control has on the radar) and sensitivity should be compatible with the expected flight regime. Controls that require manipulation while airborne should be reachable from the DEP, particularly if they must be activated in a combat environment. As an example, the Air Combat Maneuvering (ACM) Mode controls must be reachable while performing high g maneuvers and while maintaining a body position ready for safe ejection. The operative sense must be correct. The direction of activation should conform to the standards of common sense (turn the knob to the right to turn on the system) and to the standards set in references 15 and 16 (which for the most part merely put on paper the standards of common sense). The operation of the controls should be clear, requiring a minimum of operator concentration and attention. This leaves the operator free to make tactical decisions.

The controls should also be placed in logical functional groups, reducing the area of scan required to check the radar set up. The radar controls should be integrated well into the cockpit. Correct integration requires that the radar controls should operate harmoniously with the other controls within the cockpit and without hindering the simultaneous operation of other airplane systems. Integration must be evaluated during a mission relatable workload and while simultaneously operating all the other airplane systems, since good radar work is usually just a part of the mission.

Lastly, the controls should provide good tactile feedback. For example, detents should provide the proper amount of "click" and all the knobs shouldn't feel exactly alike when reaching for a control with eyes on the radar scope. Applying a little common sense and manipulating the controls in a mission relatable environment usually uncovers most of the control human factors violations.

Many modern aircraft have a large number of the avionics controls included in the Hands-On-Throttle-And-Stick (HOTAS) format, allowing manipulation without releasing the throttle and stick. These implementations have their own human factors challenges. Typical problems include the mounting of too many controls in the available area, appropriate control sensitivity across broad flight conditions and tactile feedback considerations.

The radar displays should be clearly visible from the DEP in bright daylight as well as complete darkness. In bright daylight, the display must be usable under all conditions of glare, including sunlight directly over the operator's shoulder onto the display (a particularly serious problem for most displays). In the dark, the display should not be so bright that it distracts the operator or affects his night vision. A good range of

[5] For an introduction into controls and displays human factors, see references 20, 54 and 73.

brightness control that integrates harmoniously with the rest of the cockpit is required.

The display resolution must be matched to the radar resolution. That is, the raster lines per inch versus the range scale relationship presented in equation 6 must not limit the theoretical resolution of the radar presented as equation 1. The display must refresh itself quick enough so that the symbology, alphanumerics and video present an even and continuous display without noticeable flicker. There should be no visible delay between the radar sweep passage and the update of the symbology, alphanumerics and video.

Alphanumerics must be clear and legible. The messages should be short and easily understood without excessive coding or operator interpretation. The information displayed to the operator including video, symbols and alphanumerics must be sufficient for the current phase of flight while at the same time not overloading the operator with information. This usually requires tailoring the display to the specific attack mode/mission/phase of flight, that is currently being used. The display should be assessed for the information load in a mission relatable scenario to determine its utility as an aid in the combat environment. It is unlikely that a display compatible in size, weight, power and cooling requirements with a tactical airplane will be built in the near future that has too large of a usable display face. Thus, the display should be evaluated for size in a relatable mission environment, accounting for this element of realism.

The display should be positioned in a location suitable for the mission. As an example, a display for a radar that includes ACM modes should be high on the front panel, or even on the Head Up Display (HUD), to allow the pilot to glance down or look through the HUD and gather the radar derived information while at the same time minimizing the time he or she spends with his or her eyes in the cockpit and consequently away from a visual scan for the target. As with controls, display human factors problems typically surface by applying a little common sense while using the radar in a mission relatable scenario.

2.2.2.3. Instrumentation

A tape measure and data cards are required for this test. A voice recorder is optional.

2.2.2.4. Data Required

Qualitative comments. Evaluator's anthropometric data and a list of personal flight gear worn must be recorded. The number of display raster lines per inch and range scale limits should be obtained from the radar technical manual. The usable display area should be measured. Location of the display from the DEP should be measured if a qualitative problem is noted. Record the reach length of controls that are beyond the operator's reach while seated at the DEP during any mission relatable scenario.

2.2.2.5. Procedure

Find the DEP as outlined previously. All ground and airborne tests should be performed while at this position and wearing a complete set of flight gear. Perform a system turn up on the ground outside of the hangar in a range of ambient lighting conditions (bright daylight to darkness which may be simulated using a canopy curtain). Manipulate all controls noting the factors discussed above. Measure the display usable area. Evaluate the display for the factors discussed above.

Measure and note the position and reach length to all controls and displays that pose a visibility or reach problem from the DEP. During airborne testing, manipulate the controls and make qualitative comments during mission attacks and intercepts. Take particular note during extremes of ambient lighting for displays and during high g maneuvers for controls. Confirm the results of the ground tests while airborne. Check the extremes of control limits and sensitivity. Repeat for each test flight.

2.2.2.6. Data Analysis and Presentation

Present a table of the operator's anthropometric data and the personal flight equipment worn during the tests. Present the seat position as the number of inches from the bottom of the seat travel. Relate the sensitivity of the controls to the tactical environment in which they are to be used. For example, a fighter's brightness potentiometer knob may be too sensitive to use under moderate g or turbulence making it unusable during intercepts and ACM.

Relate the accessibility, placement and grouping of the controls under mission relatable conditions. An ACM mode selector must be readily accessible while scanning outside the airplane and maneuvering violently. Relate the control clarity, operative sense and tactile feedback to a multiple threat, combat scenario requiring the operator to make quick tactical decisions. If ambient lighting affects the display in any way, relate this to the limits of the possible combat environments. Compare the minimum display resolution given in equation 6 with the minimum radar resolution given in equation 1. The display resolution should not limit the radar resolution.

Relate the information load presented the operator to the combat scenario discussed above and evaluate whether the needed information is present and whether too much information is cluttering the display. This information can include radar video, alphanumerics or symbols. This concept is closely related to the size of the display face usable area. A large scope can present more information without cluttering the display and requires less concentration to read and evaluate, especially in the case of radar video. The refresh rate should be related to the concentration required to evaluate a flickering display. The display position should be evaluated in the context of the type of information displayed, the eye position required for using the display and the display position's effect upon the scan of other displays, instruments and the outside world.

2.2.2.7. Data Cards

Sample data cards are presented as cards 3 and 4.

CARD NUMBER ___

CONTROLS

CLARITY OF OPERATION:

ACCESSIBILITY (MEASURE REQUIRED REACH IF A PROBLEM):

OPERATIVE SENSE:

ADJUSTMENT SENSITIVITY:

RANGE OF ADJUSTMENT:

TACTILE FEEDBACK:

FUNCTIONAL LOCATION/GROUPING (SKETCH IF A PROBLEM):

INTEGRATION:

Card 3: Controls Data Card

CARD NUMBER ___

DISPLAYS

[PERFORM IN BRIGHT DAY TO DARKNESS]

LOCATION QUALITATIVE COMMENTS (MEASURE LOCATION IF A PROBLEM):

CONTRAST/BRIGHTNESS/GAIN CONTROLS (RANGE OF EFFECTIVENESS):

GLARE (BOTH FROM OUTSIDE AND INSIDE COCKPIT LIGHT SOURCES):

RASTER LINES/INCH

RANGE SCALES ____/____/____/____/____

USABLE DISPLAY AREA ____ X____

RESOLUTION QUALITATIVE COMMENTS:

REFRESH RATE QUALITATIVE COMMENTS:

LOCATION OF SYMBOLOGY/ALPHANUMERICS:

INTERPRETATION OF SYMBOLOGY/ALPHANUMERICS:

INTEGRATION:

Card 4: Displays Data Card

2.3. AIR-TO-AIR RADAR TEST TECHNIQUES

2.3.1. Scan Rate

2.3.1.1. Purpose

The purpose of this test is to determine the average radar scan rate and its effect upon the utility of the radar presentation.

2.3.1.2. General

As outlined in the radar theory section, most airborne radars operate in a raster scan format. The rate at which the antenna moves from side to side determines the scan rate. Since the antenna must stop at each side and since all moving parts have some inertia, the actual scan rate varies through the scan and as the scan angle limits change. The crucial characteristic; however, is how often the sweep passes through the target's bearing and so an average scan rate over a number of scans is adequate for most purposes.[6] Scan rate can affect several radar performance factors. A quick scan rate is best to provide frequent updates of the target position, facilitating target tracking and pointing out trends in target bearing drift and range closure rate. Too quick of a scan; however, reduces the possible number of radar hits per scan for a given PRF, reducing pulse to pulse integration and thus the possibility of detection.

2.3.1.3. Instrumentation

A stop watch and data cards are required for this test. A voice recorder is optional.

2.3.1.4. Data Required

Measure the time for ten complete radar scans (one side to the other and back) at each scan angle limit setting. Record qualitative comments on the effects of scan rate upon radar detection, tracking and the maintenance of target SA.

2.3.1.5. Procedure

While on the ground, use a stop watch to measure the time for the sweep to move from one side of the display and back for ten full sweeps. Perform the test at all scan angle limit settings and repeat for one setting while airborne to confirm the ground test results. If a discrepancy occurs between the ground and airborne data, repeat for all scan angle limits. While performing mission relatable intercepts and attacks (preferably at the extremes of target closure rate and target crossing rate) qualitatively evaluate the effects of the average scan rate upon tracking, detection and the maintenance of SA. Check for all mission relatable combinations of scan angle limit and scan rate.

2.3.1.6. Data Analysis and Presentation

The average scan rate should be calculated using the following relationship:

$$Scan\ Rate = \frac{(Scan\ Angle\ Limit\ in\ deg)(20)}{(Time\ for\ 10\ Sweeps)} \qquad (7)$$

Relate problems with the target update rate to the calculated average scan rate. If tracking is not adequate, an unusually quick scan rate can be inferred as a possible cause; however, a definitive association will be beyond the scope of this test, requiring further instrumentation (tracking computer data extraction, recording and analysis).

2.3.1.7. Data Cards

A sample data card is presented as card 5.

[6] In the context used here, the average scan rate is very similar to the update rate. The use of a multiple bar scan format can further affect this distinction.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

AIR-TO-AIR SCAN RATE

[RECORD TIME FOR 10 COMPLETE SCANS.]

RADAR MODE	SCAN ANGLE LIMIT	TIME FOR 10 SWEEPS

[RECORD SCAN RATE QUALITATIVE COMMENTS ON TRACKING/DETECTION/SA.]

TARGET BEARING/RANGE ____/____

TARGET/TEST AIRPLANE COURSE ____/____

TARGET/TEST AIRPLANE SPEEDS ____/____

RADAR MODE_______________

SCAN ANGLE LIMIT ____

EFFECTS:

Card 5: Air-to-Air Scan Rate Data Card

2.3.2. Scan Angle Limits

2.3.2.1. Purpose

The purpose of this test is to determine the scan angle limits of the radar and their effects upon the utility of the radar search volume.

2.3.2.2. General

As has been discussed in the radar theory section, most airborne radars operate in a raster scan format and often have several operator selectable antenna scan angle limit selections. The largest selection is usually bounded by the physical scan angle limits of the antenna. The bounds are often set by the physical limits of the antenna against the nose cone faring covering the antenna or by line of sight interference between the radar beam and airplane structures. When a lower scan angle limit selection is made in order to concentrate the search volume, the operator is often able to slew around the center of the search volume within these limits. For these reasons, the maximum scan angle limits become critical and should be measured. The maximum limits should then be evaluated while performing a large area target search in a mission relatable situation. The critical parameter for evaluating the results becomes the maximum threat axis width and the amount of search volume needed to be covered by each airplane. During intercepts and attacks, the maximum angle off of the nose to the target expected in mission relatable tactics must be used to evaluate the scan angle limits during STT and small scan angle limit selections. The smaller scan angle limits should be measured and qualitatively evaluated during mission relatable searches where the search volume can be partially defined. The range and number of selections must be suitable for the expected mission scenarios.

2.3.2.3. Instrumentation

Data cards are required for this test with an optional voice recorder.

2.3.2.4. Data Required

Record the heading of the test airplane with the target over the nose and just at the edge of the display for each scan angle setting for both the left and right limit. Record qualitative comments concerning the utility of the maximum scan angle limit and the smaller limit selections.

2.3.2.5. Procedure

Place the target airplane at least 15 nm ahead of the test airplane heading in the same direction and speed as the test airplane. This arrangement is chosen to allow the test turn to be completed without significantly affecting the geometry to the target. At least 2000 feet of altitude separation is advisable for safety reasons. If the display is truncated at the scan angle limit selected, the range must be inside of the truncated area. Place the target just to the right or left of the nose of the test airplane with the sweep centered on the nose. Turn the test airplane slowly toward the target airplane, marking the test airplane heading as the nose crosses the target bearing and as the target passes off of the radar display. Repeat to the other side and for all scan angle limit selections. Qualitatively evaluate the effects of the maximum scan angle limits on the search volume during mission relatable situations where the threat sector is wide and with a limited number of airplanes to cover the sector. Evaluate the utility of the smaller limit selections for concentrating the search volume. Qualitatively evaluate the scan angle limits during mission relatable intercepts and attacks to ensure that contact with the target is not broken.

2.3.2.6. Data Analysis and Presentation

Subtract the bearing to the target while over the test airplane nose from the bearing as contact is lost during the left/right turns at each scan angle limit setting to determine the measured scan angle limits. Where deficiencies are noted during the qualitative evaluation of the scan angle limits, use the measured limits as supporting data. Relate the scan angle limits to their effects upon search volume during wide area search, to their effects and restrictions upon tactics as the angle to the target exceeds the scan angle limit during intercepts and to the range of selections and their utility during mission relatable search situations.

2.3.2.7. Data Cards

A sample data card is provided as card 6.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

AIR-TO-AIR SCAN ANGLE LIMITS

[PLACE THE TARGET JUST TO THE LEFT OR RIGHT OF THE NOSE AT 15 NM AND ON THE SAME HEADING. MAKE AN EASY TURN TOWARD THE TARGET. RECORD THE TEST AIRCRAFT'S HEADING AS THE TARGET PASSES THROUGH NOSE AND WHEN LOST FROM THE DISPLAY DURING THE TEST AIRPLANE'S TURN. REPEAT TO THE OTHER SIDE AND FOR EACH SCAN ANGLE LIMIT SELECTION.]

RADAR MODE	AZ LIMIT SELECTION	NOSE	L/R	LOST TARGET

[RECORD SCAN ANGLE LIMIT QUALITATIVE COMMENTS UPON THE SEARCH VOLUME AND TRACKING DURING INTERCEPT MANEUVERS.]

SCAN ANGLE LIMIT SELECTION____

TARGET RELATIVE BEARING____

TYPE OF INTERCEPT____

EFFECTS:

Card 6: Air-to-Air Scan Angle Limits Data Card

2.3.3. Elevation Angle Limits

2.3.3.1. Purpose

The purpose of this test is to determine the elevation angle limits of the radar and their effects upon the utility of the radar search volume.

2.3.3.2. General

As with the scan angle limits, the elevation angle limits of the radar are often established by the limits that the antenna can be slewed up or down. These limits can be physical, caused by space or gimbal constraints within the nose cone or by interference between the radar beam and the airplane structure. The latter is less likely for the elevation limits than for the azimuth limits.

Elevation limits are important to radar performance because they are another constraint upon the minimum detection and tracking range. Under most search situations, the elevation limits do not come into play since at medium and long range the angle to the target from horizontal will be small; however, for close targets, above or below the airplane, the maximum angle can significantly effect both detection and tracking. Two examples of situations when elevation angle limits are at issue are during ACM and airborne tanking. While maneuvering behind the target, the target must be kept within the upper and lower gimbal limits to prevent the radar from losing contact and when tracking, from breaking lock.

Generally, most modern radars will maintain detection and tracking on targets to 60° above and below the centerline. The definition of the centerline varies from airplane to airplane (airplane waterline, weapons line etc.); however, they are typically all within a few degrees. Since the upper and lower limits are critical during ACM and air-to-air refueling, the limits should be quantitatively measured to establish the numerical angular limits and then qualitatively evaluated during ACM maneuvers against a mission relatable target and during actual or simulated approaches to the tanker.

One anomaly of the radar elevation limits is noteworthy. Often the radar will track a target beyond the physical antenna limits by locking onto the target while it is in the radar antenna sidelobes. This is particularly prevalent when the target is close and the sidelobe returns are strong. A visual estimate of the angle to the target compared to the elevation angle of the antenna indicated by the radar display will quickly indicate this problem since the first strong sidelobe is often 30° to 40° off of the radar mainlobe.

2.3.3.3. Instrumentation

Data cards are required for the test with an optional voice recorder.

2.3.3.4. Data Required

Record the antenna elevation indicated by the radar display as tracking is lost for both the upper and lower limit. Note any times the angle to the target obviously exceeds the displayed angle with detection or tracking still present. Record qualitative comments concerning the maximum antenna elevation limits during ACM maneuvers and simulated or actual tanking.

2.3.3.5. Procedure

Place the target on the test airplane nose at 1/2 nm with the target at the same heading and speed as the test airplane and 1,000 feet above the test airplane. Establish STT. The test airplane should then increase speed and slowly close on the target, maintaining a constant altitude until tracking and detection is lost. Visually estimate the angle up to the target. Re-establish a 1/2 nm trail and climb the test airplane to 1,000 feet above the target, repeating the procedure for the lower gimbal limit. The test airplane will have to roll to either side to visually check the angle to the target. During ACM tests, qualitatively evaluate the utility of the gimbal limits as the target pulls inside of the test airplane (upper limit) and as the test airplane leads the target (lower limit). As time allows, attempt a simulated approach to the target as the target flies straight and level, simulating a tanker airplane. Use the recommended tanking procedures for the test airplane.

2.3.3.6. Data Analysis and Presentation

Use the radar display antenna angle at broken lock as a measure of the antenna elevation limits. Compare the measured antenna angle to the visual estimate to check for sidelobe detection or tracking. Relate the presence of sidelobe tracking to the false antenna pointing angle during ACM and tanking, and the reduced likelihood of visual detection (the operators will be led to look in the wrong direction for the target). Relate any anomalies noted during ACM or simulated or actual tanking to the possibility of broken lock or lost detection during these scenarios. Use the measured limits to back up the qualitative comments.

2.3.3.7. Data Cards

A sample data card is provided as card 7.

CARD NUMBER ___ TIME PRIORITY L/M/H

AIR-TO-AIR ELEVATION ANGLE LIMITS

[JOIN ON TARGET 1/2 NM IN TRAIL. PLACE THE TARGET AT THE SAME HEADING AND 1,000 FEET ABOVE THE TEST AIRPLANE. ESTABLISH STT. CLOSE ON THE TARGET UNTIL TRACKING AND DETECTION IS LOST. NOTE THE ANTENNA ELEVATION ANGLE UPON THE RADAR DISPLAY AND VISUALLY ESTIMATE ANGLE. REPEAT WITH THE TARGET 1,000 FEET BELOW.]

UPPER/LOWER	ANTENNA ANGLE	VISUAL ESTIMATE

[ELEVATION LIMITS QUALITATIVE COMMENTS DURING ACM AND TANKING.]

TYPE OF MANEUVER________________

EFFECTS:

Card 7: Air-to-Air Elevation Angle Limits Data Card

2.3.4. Tracking Rate Limits

2.3.4.1. Purpose

The purpose of this test is to determine the tracking rate limits for radars able to establish an STT and to determine their effects upon intercept and attack utility.

2.3.4.2. General

When an operator establishes an STT for the purposes of executing an intercept and maneuvering to an attack position it can be assumed that the target will attempt to maneuver out of the attack envelope quite vigorously. For this reason, the ability of the radar to track a target with various maneuver rates is important. The limit can be caused by a number of factors, including the angular rate with which the antenna can slew, for radars where the antenna beam is centered on the STT by pointing the antenna; the size of the tracking gate and update rate, which define the theoretical probability of achieving detection and updating the track parameters during a given maneuver; and even by the general quality of the tracking system, since a poor tracker certainly does not get better when the target maneuvers.

2.3.4.3. Instrumentation

Data cards and a stop watch are required for the test with an optional voice recorder.

2.3.4.4. Data Required

Note the time for the target to go from 45° at one side of the test airplane nose as displayed on the radar to 45° on the other side of the test airplane nose for each g level tested. Note if tracking is lost at any g level. Record qualitative comments concerning the effects of the tracking rate limits (if any are found) during mission relatable maneuvers while positioning for an attack.

2.3.4.5. Procedure

Place the target at 50° to one side of the nose at 1/2 nm with the target at the same heading and speed as the test airplane. Establish an STT. Roll the test airplane briskly but smoothly to obtain a 2g level turn toward the target, noting the g level, time from the point where the target passes through 45° on the same side of the nose to reaching 45° on the other side of the nose and note if tracking is lost during the turn. If the maximum scan angle limit is less than 50° off of the nose, smaller angles will have to be used. Repeat in 1 or 2 g increments, building up to the maximum g limit of the airplane. Next, repeat the test with the test airplane turning at the maximum g limit while the target turns in the opposite direction starting at 2 g and then at 1 or 2 g level increments to the maximum g limits of both airplanes. During mission relatable attack maneuvers, note any limitations to tactics caused by the tracking rate limits.

2.3.4.6. Data Analysis and Presentation

The average tracking rate at lost tracking can be found approximately by dividing the measured time into the number of degrees the target passes through (90° if the scan angle limits allow). The validity of the rate depends upon how precisely the g is held since transients above the g desired may leave the average tracking rate low while tracking rate transients might be high enough to break the track. Making a brisk roll to the correct angle of bank and beginning the time measurement after the g is captured prevents the initial build up in g from driving the average tracking rate too low. It is important to keep the upper g excursions as low as possible. When both aircraft are maneuvering, the start of the turns must be carefully coordinated.

If tracking is lost during the roll itself, before a tracking rate is established, the problem is most likely an antenna stabilization limit in the roll axis. A test for this parameter will be presented later. The tracking rate limit will be undefined but will probably be satisfactory if tracking is achieved within the g limits of both airplanes. If tracking is successfully broken during the test, the limit should be related to the restrictions this upper limit places on tactics. For example, the pilot may have to rely on a visual attack for violently maneuvering targets without the aid of radar derived information. More importantly, without radar illumination of the target, some weapons become unusable.

2.3.4.7. Data Cards

A sample data card is provided as card 8.

CARD NUMBER ___ TIME PRIORITY L/M/H

TRACKING RATE LIMITS

[JOIN THE TARGET 1/2 NM IN TRAIL WITH THE TARGET 50° TO ONE SIDE OF THE NOSE. PLACE THE TARGET AT THE SAME HEADING AND 1,000 FEET ABOVE THE TEST AIRPLANE. ESTABLISH STT. ROLL TO INTERCEPT A 2 G, LEVEL TURN. REPEAT AT AN INCREASING G. NOTE THE G AND TIME FOR THE TARGET TO GO FROM 45° ON ONE SIDE OF THE NOSE TO THE OTHER. REPEAT WITH THE TARGET MAKING A 2 G TURN IN THE OPPOSITE DIRECTION, AND AGAIN REPEAT AT INCREASING G.]

G TEST /TARGET AIRCRAFT	TIME	BROKEN Y/N	G TEST /TARGET AIRCRAFT	TIME	BROKEN Y/N

[TRACKING RATE LIMITS QUALITATIVE COMMENTS DURING ACM.]

TYPE OF MANEUVER ____________________

EFFECTS:

Card 8: Tracking Rate Limits Data Card

2.3.5. Antenna Stabilization Limits

2.3.5.1. Purpose

The purpose of this test is to assess the ability of the radar antenna to maintain stabilization during maneuvering flight and to determine its effect upon intercept and attack utility.

2.3.5.2. General

As discussed earlier, many radar antennas are gyroscopically or inertially stabilized in relation to the horizon within the scan and elevation limits. Realistically; however, there are limits to which the airplane can be maneuvered before this stabilization is degraded. Ideally, the radar is designed such that these constraints are beyond the maneuvering limits of the host airplane for all three maneuvering axes (roll, pitch and yaw). Measuring yaw rates in flight without instrumentation is quite difficult, thus step inputs up to the maximum allowable at a mission relatable maneuvering speed will be used instead of an actual yaw rate measurement. The loss of stabilization usually manifests itself as a degradation of detection, tracking and the radar display in general. In a search mode this usually means target misses or strobing and false alarms on the display. It is important to evaluate whether the display is still usable for detection and tracking of the target airplane during mission relatable maneuvers. Combined roll, pitch and yaw maneuvers can have their own effects upon the display and as such should also be evaluated.

2.3.5.3. Instrumentation

Data cards and a stop watch are required for the test with an optional voice recorder.

2.3.5.4. Data Required

Record the time to go from 40° nose low to 40° nose high at a constant g rate, up to the g limit of the airplane. Record the time to roll 360° at increasing stick deflections. Estimate the percent of rudder pedal throw used to achieve increasing yaw rates. During all maneuvers, make qualitative comments on the effects that the maneuvers have upon the radar display and detection performance. Record the same qualitative comments during rolling push-overs and pull-ups. Record qualitative comments concerning the effects of the antenna stabilization limits (if any are found) during mission relatable maneuvers and while positioning for an attack. Record whether in STT or search mode for all tests.

2.3.5.5. Procedure

Position the target 10 to 15 nm ahead of the test airplane at the same heading and speed and 1,000 feet above the test airplane. Establish a normal search mode, single bar pattern and a medium to narrow scan angle limit to allow a frequent update of the scan volume during the maneuvers. Establish radar contact with the target. Maneuver to 50° nose low and establish a 2g pull-up to 50° nose high at a constant 2g rate. Mark the time while passing from 40° nose low to 40° nose high. Note any degradation in detection of the target during the maneuver and any degradation of the display. If the elevation angle limits are less than 50°, then a smaller maneuver will have to be performed to maintain contact with the target. Repeat the test at increasing g levels until degradation is noted or the g limit of the airplane is reached.

Turn to place the target 20° off of the nose. Roll the airplane 360° at 1/4 stick deflection, noting the time to complete the roll and any degradation in detection or the display. Repeat at 1/2, 3/4 and full stick deflection if airplane limits allow. With the target again on the nose, perform a step input of the rudder at 1/4 deflection. Note any degradation of detection or the display. Repeat at 1/2, 3/4 and full rudder deflection if the airplane's limits allow.

If no degradation is noted while performing the tests above, perform a series of rolling push-overs and pull-ups at increasing g rates until the limits of the airplane are reached. Again, look for degradation in detection or the radar display. Repeat all three portions of the test while tracking the target in STT mode. During mission relatable intercepts and attack maneuvers, note the effects upon tactics of the limits found above.

2.3.5.6. Data Analysis and Presentation

Divide the time to perform the pitch up maneuvers into the 80° covered to obtain the pitch rate. Divide the time to roll into 360° to get the average roll rate.

If no degradation is noted within the maneuvering limits of the airplane during the single axis or the multiple axis maneuvers, then the stabilization limits are probably satisfactory. If degradation is noted they should be related to the limits that this degradation imposes upon tactics. The amount of limitation depends upon the axis involved (a pitch axis limit of 2g on an 8g airplane would obviously be more serious than a yaw axis limit of 1/4 rudder deflection) and the level at which the degradation is noted. These limitations should be verified during mission relatable intercepts and attacks.

2.3.5.7. Data Cards

Sample data cards are provided as card 9.

CARD NUMBER ___ TIME PRIORITY L/M/H

AIR-TO-AIR ANTENNA STABILIZATION LIMITS

[JOIN THE TARGET 10-15 NM IN TRAIL WITH THE TARGET AT THE SAME SPEED AND HEADING AND 1,000 FEET ABOVE. ESTABLISH RADAR CONTACT IN SEARCH, SINGLE BAR AND A MEDIUM SCAN ANGLE LIMIT. PITCH DOWN TO 50° LOW AND PULL-UP AT 2G TO 50° NOSE HIGH. TIME 40° LOW TO 40° HIGH. NOTE ANY DEGRADATION. REPEAT AT INCREASING G RATES.]

MODE	TIME TO PITCH	G	DEGRADATION

[TURN TO PLACE THE TARGET 20° OFF OF THE NOSE. ROLL AT 1/4 STICK DEFLECTION. NOTE THE TIME TO ROLL 360° AND ANY DEGRADATION. REPEAT AT 1/2, 3/4, FULL DEFLECTION.]

MODE	TIME TO ROLL	G	DEGRADATION

Card 9: Air-to-Air Antenna Stabilization Limits Data Cards

AIR-TO-AIR ANTENNA STABILIZATION LIMITS

[TURN TO PLACE THE TARGET ON THE NOSE. PROVIDE A STEP INPUT OF RUDDER AT 1/4 DEFLECTION. NOTE ANY DEGRADATION AND REPEAT AT 1/2, 3/4 AND FULL DEFLECTION.]

MODE	RUDDER INPUT	DEGRADATION

[PERFORM EASY ROLLING PUSH-OVERS AND PULL-UPS NOTING ANY DEGRADATION. REPEAT AT INCREASING G LEVELS UNTIL DEGRADATION IS NOTED OR THE AIRPLANE LIMITS ARE REACHED.]

DESCRIBE THE MANEUVER (CONTROL DEFLECTIONS, G LEVELS ETC.):

MODE:

DEGRADATION:

[REPEAT WHILE TRACKING THE TARGET IN STT.]

[EVALUATE THE ANTENNA STABILIZATION LIMITS DURING MISSION RELATABLE INTERCEPTS AND ATTACK MANEUVERS.]

MODE:

TYPE OF MANEUVERS:

DEGRADATION:

Card 9: Air-to-Air Antenna Stabilization Limits Data Cards (Continued)

2.3.6. Minimum Range

2.3.6.1. Purpose

The purpose of this test is to determine the minimum radar detection and tracking ranges and to determine the effect of this range upon ACM tactics and airborne tanking procedures.

2.3.6.2. General

The theoretical minimum radar range was discussed in the radar theory section. The theoretical minimum range is the absolute best the radar can achieve. Realistically, there are other factors that often cause this number to grow beyond the theoretical minimum. The display can play an important part, particularly in the case of a PPI display. As the detection video closes into the notch of the PPI display, videos can become unusable to the operator since all the noise is also compressed into this small area of the display. For a B scan format, the problem is relieved somewhat since the azimuth is spread out at the bottom of the display but display distortion can still be a factor.

Minimum tracking range is limited first by the minimum theoretical detection range and will not be less than this range. A number of other factors also come into play, including the quality of the tracker and its ability to handle the rapid changes in target azimuth that can occur at close ranges. The minimum detection range is almost always better than the minimum tracking range; however, for a non-maneuvering target, modern trackers are becoming good at close target tracking and the minimum detection and tracking ranges are usually close to each other. Since the tracking range is usually the limiting factor, time can be saved by checking this limit and if it is adequate, assuming the detection will also be adequate. Minimum detection and tracking ranges can be mission related to the requirement to close on a possible hostile target to gain a Visual Identification (VID) in poor visibility, the most restrictive minimum weapons release range (usually a gun limit), and the requirement to close on a tanker aircraft in poor visibility.

2.3.6.3. Instrumentation

Data cards are required for this test with an optional voice recorder.

2.3.6.4. Data Required

Record the radar derived range at which the radar loses tracking on the target and the range at which detection is no longer held on the target. During mission relatable ACM, intercepts and simulated or actual tanking, qualitatively evaluate the effects of the minimum detection and tracking ranges upon the utility of the radar.

2.3.6.5. Procedure

Position the target 1/2 nm ahead of the test airplane at the same heading and speed and 1,000 feet above the test airplane. Establish radar contact and an STT. Slowly close on the target. When visual contact is achieved, climb to the target's altitude and continue to close on the target until tracking is dropped or a minimum of 300 feet separation. The 300 feet "bubble" may be broken and the test airplane may close to a lesser range if both pilots and airplanes are formation qualified, and the pilot in the test airplane is not the operator concentrating on the radar. If weather is such that visual contact cannot be maintained, the test airplane should immediately descend to 1,000 feet below the target airplane. After completing the test in STT mode, establish the shortest range scale search mode and reduce airspeed slightly to open the range slowly until detection of the target is achieved. During mission relatable ACM, intercepts and simulated or actual tanking, note the effects of the limitations above upon mission tactics.

2.3.6.6. Data Analysis and Presentation

Use the radar derived ranges at broken STT lock and at initial search mode detection as the minimum tracking and detection ranges. Relate the minimum ranges to their effects upon Instrument Meteorological Conditions (IMC) intercepts for VID, the minimum range for the shortest range weapon system that the airplane can carry (will probably be guns), and to IMC tanking procedures.

2.3.6.7. Data Cards

A sample data card is provided as card 10.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

AIR-TO-AIR MINIMUM DETECTION AND TRACKING RANGE

[JOIN THE TARGET 1/2 NM IN TRAIL WITH THE TARGET AT THE SAME SPEED AND HEADING AND 1,000 FEET ABOVE. ESTABLISH STT AND SLOWLY CLOSE. CLIMB TO THE TARGET'S ALTITUDE WITH A VISUAL. CONTINUE TO CLOSE TO A BROKEN LOCK OR A ___ FEET MINIMUM. ESTABLISH A MINIMUM SCALE SEARCH MODE. OPEN UNTIL DETECTION.]

MODE	RANGE	LOST/GAIN	DEGRADATION

[EVALUATE THE EFFECTS OF THE MIN RANGES ON ACM, INTERCEPT AND TANKING TACTICS.]

MINIMUM WEAPONS RANGE___________________

EFFECTS:

ACM EFFECTS:

TANKING EFFECTS:

Card 10: Air-to-Air Minimum Detection And Tracking Range Data Card

2.3.7. Range and Bearing Accuracy

2.3.7.1. Purpose

The purpose of this test is to determine how accurately the radar can determine the target's range and bearing and to qualitatively evaluate the effects this accuracy has upon mission relatable intercepts and attacks.

2.3.7.2. General

An accurate measurement of radar range and bearing accuracy requires an outside source of space positioning information for both the target and the test airplane. Additionally, a precise determination of range and bearing accuracy can be important for two reasons. First, the radar derived range is used in several of the other test techniques. Any errors in radar range can thus contribute to errors in other test data. Second, when used for poor weather join-ups for VID and for tanking, the pilot needs to know radar ranges accurately in order to execute a safe intercept. For these reasons, strong consideration should be given to the use of accurate space positioning truth data in this test.

A rough check of range and bearing accuracy without space positioning data is available in cases where the more accurate test is not required. As with all the other tests, the critical factor is the utility of the parameters in a mission relatable scenario. If the range and bearing accuracy is qualitatively evaluated to be sufficient in this environment, the rough numbers that this procedure will obtain are sometimes sufficient. If it fails, a more expensive test will be required; however, this test can still be used to gain some insight to support the qualitative assessment. All that is required for the test is that both the test and target aircraft be Tactical Air Navigation (TACAN) equipped. However, if the target is equipped with a radar of known good range and bearing accuracy it can be used to refine the measurements. Care should be taken such that the test and target aircraft radars are sufficiently separated in frequency to prevent casual interference with the test system.

Since we are concerned with the range and bearing information available to the operator, the format and quality of the radar display can have a significant influence upon the accuracies. During STT the radar often provides a digital display of the range and bearing which eliminates the errors associated with reading the radar display's graphical scales. Often the range and bearing to a cursor is available in the search mode. If a cursor is available in the search mode it should be used for the test since it will increase the range and bearing display accuracy over an estimate using the display scale.

The accuracy should be tested in both the search and STT modes. The results are often different. The smallest range scale that still displays the target should be used when reading bearing and ranges from the scales without the aid of digital readouts since the smaller scale will allow for more accurate reading. The range and bearing accuracies should be qualitatively evaluated during mission relatable intercepts and attacks to assess the utility of the information supplied to the operator for the accomplishment of the mission.

2.3.7.3. Instrumentation

Data cards with an optional voice recorder will be required for this test. If a target with a previously tested radar is available, it should be used.

2.3.7.4 Data Required

Record the TACAN position of both the target and test airplane and the radar derived range and bearing to the target. If the target is radar equipped, record the target and test airplane derived bearing and ranges to each other. During mission relatable intercepts and attacks, record qualitative comments concerning the effects of the accuracy of the range and bearing information supplied to the operator.

2.3.7.5. Procedure

For a target airplane without a radar, place the target and test airplanes on the same radial from a prebriefed TACAN station at 30 to 40 nm separation. Fly the target and test airplanes on headings necessary to maintain the same radial from the TACAN station with the target 1,000 feet above the test airplane. The airplanes should be heading towards each other. Establish radar contact with the target in search mode. On a mark given by the test airplane, the test airplane should record the radar derived bearing and range to the target and the TACAN bearing and range. Simultaneously, the target should record its TACAN bearing and range. Establish an STT and repeat the procedure. If the target has a radar, have the target establish an STT on the test airplane and also record the range and bearing to the test airplane at the same time that the TACAN position is recorded.

2.3.7.6. Data Analysis and Presentation

Since both airplanes are on the same TACAN radial, the bearing to the target is the radial or its reciprocal. This bearing should be compared to the radar derived bearing. The TACAN derived radial within the two aircraft is designed to have an accuracy of 3° to 4° and so the truth data will have the same accuracy given that both pilots fly the same indicated radial. [Ref. 38:p, 2.74].

The TACAN derived Distance Measuring Equipment (DME) mileages can be subtracted to gain the range to the target and then compared to the radar derived range. The TACAN derived range truth data will have approximately 0.5 nm of accuracy [Ref. 38:p. 2.74]. If a radar equipped target is used that has had full radar range and bearing accuracy tests performed, the reciprocal bearing and the radar derived range can be used as the truth data with an accuracy equal to the tested accuracy of the target airplane's radar.

During mission relatable intercepts and attacks, the radar derived range and bearing information should be evaluated for their utility in affecting the intercept and for the effects that the largest measured error will have upon weapons acquisition and accuracy. The effects upon tactics should then be related.

2.3.7.6. Data Cards

A sample data card is provided as card 11.

CARD NUMBER ___ TIME PRIORITY L/M/H

AIR-TO-AIR RANGE AND BEARING ACCURACY

[POSITION THE TARGET AND THE TEST AIRPLANE ON THE ___ RADIAL OF THE ___CHANNEL TACAN HEADING TOWARDS EACH OTHER. VARY THE HEADINGS SLIGHTLY TO MAINTAIN THE RADIAL WITH THE TARGET 1,000 FEET ABOVE THE TEST AIRPLANE. ESTABLISH RADAR CONTACT IN SEARCH MODE IN THE TEST AIRPLANE AND WITH STT IN THE TARGET AIRPLANE. ON THE TEST AIRPLANE'S CALL, BOTH AIRCRAFT RECORD TACAN BEARING/RANGE AND RADAR DERIVED BEARING/RANGE TO EACH OTHER. REPEAT WITH THE TEST AIRPLANE IN STT.]

TARGET TACAN BEARING/RANGE	TEST TACAN BEARING/RANGE	TARGET RADAR BEARING/RANGE	TEST RADAR BEARING/RANGE

[EVALUATE RADAR BEARING AND RANGE QUALITATIVELY DURING MISSION RELATABLE INTERCEPTS AND ATTACKS.]

TACTIC:

EFFECTS:

Card 11: Air-to-Air Range And Bearing Accuracy Data Card

2.3.8. Range and Bearing Resolution

2.3.8.1. Purpose

The purpose of this test is to determine how well the radar can resolve two targets closely spaced in azimuth and range, and to determine the effect these resolution limits have upon mission relatable intercepts and attacks.

2.3.8.2. General

Theoretical range and azimuth resolution are discussed in the radar theory section. The radar display can have a pronounced affect upon resolution. Resolution is important for an air-to-air radar because it allows the operator to determine the number of aircraft flying in formation or in the case of a doppler VS mode, closely spaced in azimuth alone. This function is known as "raid count". The raid count in turn affects the tactics used during an intercept and the number of fighters committed to each "cell" of incoming aircraft.

Range and bearing resolution measurements require external space positioning data. Space positioning data is required because precise time histories are needed for the location of three different aircraft simultaneously, allowing accurate determination of the difference in azimuth and range of two different radar targets. The dependency of the test procedure upon extensive space positioning data violates the basic assumptions for the development of these test procedures; however, the test is described here for completeness.

Most radars inherently have better range resolution than azimuth resolution. For this reason, during the azimuth resolution test, target placement is crucial. If either target gets closer in range than the other, it is possible for the targets to break out in range. The appearance is that the target broke out in azimuth when it, in fact, broke out in range. This makes the azimuth resolution appear to be better than it actually is. Space positioning ranges typically allow for close control of the test aircraft and targets. Close control can be used to ease the correct placement of the targets for the test.

2.3.8.3. Instrumentation

Data cards and an optional voice recorder are required for this test. Instrumentation is required to precisely track the test and two target airplanes and to record time correlated space positioning data on all three. Typically, the ground based tracker requires an electronic beacon to be installed on the test airplane and targets.

2.3.8.4. Data Required

The ground based tracker is required to provide a recording of the precise, time tagged, geographic location of the test airplane and both targets. Typically, the positions are recorded at greater than several times per second to an accuracy of less than 20 feet. The evaluator, within the test airplane, must record the precise time when the targets are broken out in azimuth and range for each radar mode tested.

2.3.8.5. Procedure

Immediately prior to the test, have the ground tracking station perform a precise time synchronization of the time source within the ground station and within the test airplane. Place the target airplanes 10 to 30 nm ahead of the test airplane on the same or a reciprocal heading and 1,000 feet above the test airplane. Have the targets join in a 50 feet trail or the minimum allowed considering the qualifications of the airplanes and crew for formation flying and the visibility/cloud layers. Establish radar contact in search mode, narrowing the search scan angle limits after initial detection and use a single bar scan pattern. On the test airplane's call, the trail target should reduce speed slightly to slowly open on the lead target, ensuring the lead target is still directly on the nose to maintain azimuth alignment between the test airplane and the targets. The evaluator must record the precise time when two distinct radar targets are first noticed. If visual contact is lost between the targets, the trail should climb 1,000 feet (without gaining airspeed) and the test discontinued. Repeat the test for all radar modes that affect the radar pulse width.

When breakout occurs and the data is taken, the test airplanes should maneuver to a side by side (abeam) position with approximately 500 feet of separation. The targets and test airplane should be heading towards each other for this portion of the test. The targets should be at the same altitude as long as visual contact is maintained. If visual contact is lost between the targets, one target should climb 1,000 feet and the test discontinued. The beginning range for the test should be at least as great as the range required to ensure breakout will not occur using the theoretical resolution limit discussed in the radar theory section. The following relationship applies:

$$R_{test\ begin}=(0.1nm)\tan(\theta)$$
$$R_{test\ begin}=\text{range for the beginning of the test}$$
$$\theta=\text{test radar advertised antenna beamwidth} \tag{8}$$

The targets should continue inbound until the second target is broken out on the test radar display. The precise time at which two distinct radar targets are noticed should be recorded by the evaluator.

2.3.8.6. Data Analysis and Presentation

The space positioning data is typically provided in the form of precise latitude and longitude. The range to each target and the angle between the two targets can be derived from a knowledge of the test airplane and target airplane latitude and longitude at any given time using equation (9). The calculations must be performed for each target at the times of range and azimuth breakout. The difference between the target ranges at breakout during the range resolution tests is then the measured range resolution and the difference in azimuth between the two targets at breakout during the azimuth resolution tests is then the azimuth resolution.

$$\Delta_{lat}=|\text{latitude of test airplane}-\text{latitude of target airplane}|$$
$$\Delta_{long}=|\text{longitude of test airplane}-\text{longitude of target airplane}|$$
$$avg_{lat}=\left[\frac{(\text{latitude of test airplane}+\text{latitude of target airplane})}{2}\right]$$
$$R_{target}=\sqrt{[(\Delta_{lat})(6076)]^2+[(\Delta_{long})(\cos(avg_{lat}))(6076)]^2}$$
$$R_{target}=\text{range ro either target as applicable}$$
$$R_{resolution}=|R_{target1}-R_{target2}|$$
$$R_{target1}=\text{range to target 1}$$
$$R_{target2}=\text{range to target 2}$$
$$\Delta_{lat1-2}=|\text{latitude target 1}-\text{latitude target 2}|$$
$$\Delta_{long1-2}=|\text{longitude target 1}-\text{longitude target 2}|$$
$$avg_{lat1-2}=\left[\frac{(\text{latitude target 1}+\text{latitude target 2})}{2}\right]$$
$$R_{target1-2}=\sqrt{[(\Delta_{lat1-2})(6076)]^2+[(\Delta_{long1-2})(\cos(avg_{lat1-2}))(6076)]^2}$$
$$\Delta_{res}=\arctan\left[\frac{R_{target1-2}}{\left(\frac{(R_{target1}+R_{target2})}{2}\right)}\right]$$
$$R_{target1-2}=\text{range between target 1 and target 2}$$
$$\Delta_{res}=\text{measured angular resolution of the radar}$$
$$\text{all }\Delta_{lat}\text{ and }\Delta_{long}\text{ in minutes}$$
$$\text{all }avg_{lat}\text{ in degrees} \tag{9}$$

Relate the range and azimuth resolution to the expected tactics of the threat and from this assess the radar's ability to perform a raid count. Qualitatively assess the effect of the expected raid count capability upon intercept and attack tactics, particularly on the assignment of fighters to inbound cells and the optimization of attack tactics.

2.3.8.7. Data Cards

A sample data card is provided as card 12.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

AIR-TO-AIR RANGE AND BEARING RESOLUTION

[SYNCHRONIZE TIME TO THE GROUND STATION TIME SOURCE. POSITION THE TARGETS ON THE NOSE AT 10 TO 30 NM HEADING TOWARDS OR AWAY AND 1,000 FEET ABOVE THE TEST AIRPLANE. PLACE THE TEST RADAR IN SEARCH MODE, NARROWEST SCAN ANGLE PATTERN AND SINGLE BAR SCAN. THE TRAIL OPENS SLOWLY UNTIL THE TEST RADAR BREAKS OUT TWO TARGETS. RECORD DATA. REPEAT FOR ALL MODES AFFECTING PULSE WIDTH.]

MODE	TIME

[PLACE THE TARGETS IN A 500 FEET LINE ABREAST WHILE HEADING TO CLOSE. USE A __NM SEPARATION TO START. CONTINUE INBOUND UNTIL BREAKOUT OCCURS. RECORD TIME.]

TIME AT BREAKOUT ________

Card 12: Air-to-Air Range And Bearing Resolution Data Card

2.3.9. Maximum Detection Range

2.3.9.1. Purpose

The purpose of this test is to determine the maximum detection range for a target with a radar cross section similar to a mission relatable target and to evaluate the impact of this detection range upon intercept tactics.

2.3.9.2. General

Maximum detection range is a major yardstick of radar performance since one of the uses of air-to-air radar is to extend the surveillance envelope of the airplane beyond the visible range. As outlined in the radar theory section, the maximum radar detection range is influenced by a large number of factors, including the radar cross section of the target. Since exhaustive tests of a number of targets is beyond the scope of this test technique, it is very important to choose a target similar in radar cross section to the threat aircraft. This allows us to make a qualitative assessment of the maximum detection range in a mission relatable environment and then to support that assessment with mission relatable empirical data.

For the purposes of this test, the maximum detection point will be defined as the range at which the radar declares a hit on the target (or the operator can resolve a target hit in the case of an analog system display) for 50% of the antenna scans. The 50%, 0.5 "blip/scan" or Probability of Detection (PD) 0.5 requirement eliminates the possibility of the maximum detection range being defined at a point where a few spurious hits at long range are achieved. These spurious hits can occur for a number of reasons including test day atmospherics (ducting) and multi-path reinforcements of the long range return signal. Maximum detection range is often different for targets above than below the test airplane altitude due to the effects of clutter. In most cases both situations are important and mission relatable and should be measured. In addition, more than one long range mode is sometimes available on the same radar such as when a long range, pulsed TWS mode is available with a long range, VS doppler mode. Both modes should be tested.

2.3.9.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.3.9.4. Data Required

Record the meteorological conditions for the test (including the altitude of all visible moisture layers). Record the target type and external configuration. Record the radar mode and the range at which a blip/scan ratio of 0.5 is estimated. During mission relatable intercepts, record the effects that the maximum detection range have upon intercept tactics.

2.3.9.5. Procedure

Place the target airplane on the nose at a range beyond the maximum displayable range of the radar (it is often possible to use a shorter range in cases where the radar has been flown before and rough maximum range data is available). The target should be on a reciprocal heading and 1,000 feet above the test airplane. Use a search mode, a medium to narrow azimuth scan limit and a single bar pattern. Perform the test with the TACAN in the air-to-air mode to determine target range. Compare the radar display with the TACAN range to the target, estimating when the blip/scan ratio is approximately 0.5. Record the range when the blip/scan ratio reaches 0.5. Repeat for any other long range search modes (usually includes a pulse or pulse doppler and a pure doppler VS mode). Descend the target to a low altitude, usually 500 feet Above Ground Level (AGL) is low enough while not compromising safety and repeat the test to determine the effects of clutter. For pulse doppler modes, choose the target and test airplane airspeeds to stay well clear of closure rates that place the target in radar blind speeds. Blind speed are discussed in detail in section 2.3.15. Closure rates can be converted to indicated airspeeds using the set of equations in section 2.3.13. During mission relatable intercepts, note the effects that the detection ranges have upon intercept tactics.

2.3.9.6. Data Analysis and Presentation

Using the test radar frequency, target configuration and aspect (essentially nose-on with this technique) derive the radar cross section of the target. Cross section versus aspect plots for various frequency bands exist for virtually every military target. If the target cross section is not the same as the value to which the radar is being tested, adjust the maximum detection range using equation 10. In most cases this is not necessary since the radar performance specifications are often written to match the general cross section of the threat as well as the available target fleet.

$$R_{\max adj} = R_{\max test}\left(\frac{\sigma_{desired}}{\sigma_{test}}\right)^{\frac{1}{4}} \qquad (10)$$

Care should be taken in applying equation (10) to situations where the cross sections differ by much greater than an order of magnitude. Is should also be noted that the maximum detection range can sometimes vary greatly from one data point to the next. Usually, a statistically significant set of data points are required. Sample size selection depends mainly upon the variance of the measurements from one test to the next and is discussed in detail in references 43 and 72.

Relate the maximum detection ranges to the amount of time and airspace available to maneuver to optimize attack tactics and compare the maximum detection range to the maximum range of the weapons carried. Finally, compare the maximum detection range to the capabilities of the threat and the expected advantages in tactics for the aircraft with the longest radar detection range. Compare the ranges of the different modes in both the heavy clutter and non-clutter environment to ensure the modes designed for each environment are compatible with the mission of the airplane (VS will usually do much better in clutter than a pulse or even pulse doppler mode).

2.3.9.7. Data Cards

A sample data card is provided as card 13.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

AIR-TO-AIR MAXIMUM DETECTION RANGE

[POSITION THE TARGET ON THE NOSE AT ___ NM HEADING INBOUND AND 1,000 FEET ABOVE THE TEST AIRPLANE. SET UP IN SEARCH MODE, A MEDIUM OR NARROW SCAN ANGLE LIMIT, RANGE SCALE ADEQUATE TO COVER THE TARGET RANGE AND SINGLE BAR. SET UP THE AIR-TO-AIR TACAN. NOTE THE RANGE AT PD=0.5. REPEAT IN THE VS MODE. REPEAT WITH THE TARGET AT ___ FEET AGL.]

TARGET TYPE AND CONFIGURATION____________________________________

____

VISIBLE MOISTURE LAYERS, ALTITUDE AND TYPE ______________________

____

MODE	TARGET ALT	RANGE PD=0.5	TACAN RANGE

[EVALUATE THE EFFECTS OF THE MAXIMUM DETECTION RANGES DURING MISSION RELATABLE INTERCEPTS.]

EFFECTS:

Card 13: Air-to-Air Maximum Detection Range Data Card

2.3.10. Maximum Unambiguous Range

2.3.10.1. Purpose

The purpose of this test is to determine the maximum unambiguous range of the radar and its effects upon intercept tactics.

2.3.10.2. General

The radar theory section outlines the relationship between range ambiguities and radar PRF. Although the PRF is easily checked on the ground, it is worthwhile to perform a quick check for range ambiguities within the maximum detection envelope of the airplane while airborne, particularly for airplanes with multiple or staggered PRFs. Since range ambiguities tend to come into play at longer ranges, the test should be performed using the long range modes. Check the pulse, pulse doppler, and FM ranging modes only since the VS mode does not determine range. If no irregularities are found in the longer range modes, then the validity of the ground PRF checks for the other modes can be assumed.

Since the target must be acquired to check the range validity, a little creativity may be required to confirm contact with the correct radar target if range ambiguities actually exist. If an STT can be established, the target bearing and altitude can be used to identify the target. Heading and speed may be incorrect depending upon the method used for tracking. Altitude will also be affected since a simple geometrical relationship between antenna pointing angle and range is usually used to determine altitude; however, the altitude error should be small if the difference between the target and test altitudes is small. A quick call to the agency controlling the test area can be used to confirm that no other aircraft are along the same line of bearing and if they are, their altitude.

2.3.10.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.3.10.4. Data Required

If a discrepancy of greater than 3 nm between radar range and air-to-air TACAN range is noted, record the radar and air-to-air TACAN derived target ranges every 2 nm of closure until the target and test airplane pass or "fly through". Record qualitative comments of the effects of ambiguous ranges (if any are found) during mission relatable intercepts.

2.3.10.5. Procedure

Following a maximum detection range data point, obtain an STT. If a range ambiguity is present, use the target bearing and altitude, as well as aid from the test area controlling agency to confirm the correct target is acquired. If a range difference of greater than 3 nm between the air-to-air TACAN and the radar is noted, begin recording the radar and TACAN derived ranges every 2 nm of closure. Continue taking data until fly through. Repeat for all long range, ranging modes.

2.3.10.6. Data Analysis and Presentation

Plot the radar derived range versus the air-to-air TACAN derived target range. If an ambiguity is present, a sawtooth pattern will be evident. The pattern will be repetitive and symmetrical if the PRF is constant. The approximate PRF can be derived from the plot using the following relationship:

$$PRF=\frac{(C)}{(R_{rep})} \qquad (11)$$

R_{rep}=*the TACAN derived range from the beginning of the peak of the sawtooth*

If the PRF is staggered or random, a symmetrical, repeatable pattern may not be evident but the sawtooth shape should still be seen. If an ambiguity is found, relate the poor range information to its effect upon intercept and attack tactics. If target heading, speed or altitude are affected, relate the quality of this data to the same mission relatable intercept tactics.

2.3.10.7. Data Cards

A sample data card is provided as card 14.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

MAXIMUM UNAMBIGUOUS RANGE

[FOLLOWING THE MAX DETECTION RANGE TEST, ESTABLISH STT. USE THE TARGET'S BEARING, ALTITUDE AND ADVISORY CALLS TO CONFIRM THE CORRECT TARGET IS ACQUIRED. IF THE TACAN AND RADAR RANGES ARE DIFFERENT BY GREATER THAN 3 NM, TAKE BOTH RANGES EVERY 2 NM. NOTE THE QUALITY OF THE RADAR DERIVED COURSES, SPEEDS AND ALTITUDES.]

TACAN	RADAR	TACAN	RADAR	TACAN	RADAR	TACAN	RADAR

[IF AMBIGUITIES ARE FOUND, QUALITATIVELY EVALUATE THE EFFECTS OF ERRONEOUS RADAR RANGES AND TARGET DERIVED COURSE, SPEED AND ALTITUDE ON TACTICS DURING MISSION RELATABLE INTERCEPTS.]

EFFECTS:

Card 14: Maximum Unambiguous Range Data Card

2.3.11. Maximum Acquisition Range

2.3.11.1. Purpose

The purpose of this test is to determine the maximum range at which the radar, if equipped with an STT mode, can acquire a track and to assess the effect that this parameter has upon intercept tactics.

2.3.11.2. General

Radar tracking is discussed in the radar theory section. Even with a TWS mode, once a target is chosen for intercept, it is often appropriate to establish an STT to increase the detection level and quality of the course, speed and altitude calculations. In addition, many radars will optimize the PRF and range scales automatically once an STT is acquired and tracking begins. It is desirable to be able to establish an STT immediately upon detection to allow the greatest intercept flexibility.

2.3.11.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.3.11.4. Data Required

Following a maximum detection range data point, record the radar and air-to-air TACAN derived ranges at which an STT can be established. During mission relatable intercepts, record qualitative comments concerning the effects that the maximum acquisition range has upon intercept tactics.

2.3.11.5. Procedure

Perform a maximum detection range test. After the PD=0.5 point, attempt to designate the track for STT. If unsuccessful, allow the detection level and antenna scan pattern to stabilize for a couple of scans and then attempt again. Continue until an STT is acquired. Record the acquisition range as displayed on the radar and the air-to-air TACAN.

2.3.11.6. Data Analysis and Presentation

Adjust the maximum acquisition range for the target radar cross section as per the maximum detection range section 2.3.9. It should be noted that the maximum acquisition range can sometimes vary greatly from one data point to the next. Usually, a statistically significant set of data points are required. Sample size selection depends mainly upon the variance of the measurements from one test to the next and is discussed in detail in references 43 and 72.

For a non-TWS radar, relate the availability of an STT at long range to the requirement for course and speed information to optimize intercept geometry and even to evaluate the level of threat that the target poses (a high speed inbound target usually is more urgent than one heading away). For TWS radars, relate the accuracy of the tracking parameters and the probability of continuous detection all the way to intercept, to the optimization of intercept tactics. If the detection and acquisition ranges are near equal, the STT range is optimized.

2.3.11.7. Data Cards

A sample data card is provided as card 15.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

MAXIMUM ACQUISITION RANGE

[PERFORM A MAXIMUM DETECTION RANGE TEST. AFTER THE PD=0.5 POINT IS TAKEN, ATTEMPT STT. REPEAT UNTIL THE STT IS ESTABLISHED. RECORD THE RADAR AND AIR-TO-AIR TACAN RANGES.]

RADAR STT RANGE	TACAN STT RANGE

[EVALUATE THE EFFECTS OF THE MAXIMUM ACQUISITION RANGE DURING MISSION RELATABLE INTERCEPTS.]

EFFECTS:

Card 15: Maximum Acquisition Range Data Card

2.3.12. Blind Ranges

2.3.12.1. Purpose

The purpose of this test is to find any blind ranges within the detection envelope of the radar and then to evaluate the effect that these blind ranges have upon intercept tactics.

2.3.12.2. General

In some pulsed radars, the PRF is increased beyond the limit where the maximum unambiguous range is less than the maximum detection range. This is done to increase the average power of the radar. The ambiguity can be resolved in a number of ways, as discussed in the radar theory section. A side effect of these techniques is the generation of range blocks where detection is lost. These blind range blocks are usually small and sometimes unnoticeable. It is still worthwhile to check for them. The problem is compounded for VS modes since the transmit pulses, and thus blind range blocks, tend to be very long. The effect is minimized through techniques like staggering the PRF on a pulse to pulse basis to move the blind range in a correspondingly staggered fashion and prevent long, multiple scan drop-outs. If the blind ranges are wide, they can cause the pilot to commit on an intercept and then to lose contact at critical ranges, allowing the target to optimize his own intercept while the test radar is without detection or "in the blind".

2.3.12.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.3.12.4. Data Required

Following the maximum detection range data point, note whenever the target is lost and then reacquired.

2.3.12.5. Procedure

Perform a maximum detection range test. After the initial PD=0.5 data point, maintain a search mode with a medium to narrow scan pattern, single bar and the minimum range scale able to maintain radar contact. Ensure that the antenna elevation is centered on the target altitude at the target range. Monitor the detection from scan to scan and note, using the radar and air-to-air TACAN, the ranges where detection is lost and then, the range where it is regained. Repeat this test as many times as possible during the course of the flight. During mission relatable intercepts, note any detection drop-outs and their effects upon intercept tactics.

2.3.12.6. Data Analysis and Presentation

Detection drop-outs are not uncommon and will probably never be completely eliminated. For this reason, more than one run will be required to establish a pattern of blind ranges. Two problems should be looked for. Qualitatively, the detection level should be adequate to provide good SA to the operator throughout the intercept. Relate the width and number of drop-outs to their effects upon intercept tactics. Staggered PRFs and/or PWs will cause the drop-outs to occur randomly and can only be assessed quantitatively with extensive instrumentation. An analysis of the manufacturer's technical material will tell whether a staggered PRF and/or PW scheme is used. When the radar parameters are constant, the blind ranges will be fairly repeatable and even with other random drop-outs, will be seen by plotting the detection dropouts on a detection versus range plot. Consistent misses will occur at the same beginning and end points with the random dropouts scattered over the rest of the detection volume. The random drop-outs will be more prevalent at the longer ranges, where detection is more difficult. Relate the width and ranges of the blind ranges to their effects upon intercept tactics. Try to relate them to specific critical weapon ranges such as maximum launch and optimum launch ranges and also to the weapons parameters of the threat.

2.3.12.7. Data Cards

A sample data card is provided as card 16.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

BLIND RANGES

[PERFORM A MAXIMUM DETECTION RANGE TEST. USE A SEARCH MODE, MEDIUM TO NARROW SCAN PATTERN, SINGLE BAR, AND THE LOWEST RANGE SCALE TO COVER THE TARGET. AFTER THE PD=0.5 POINT IS TAKEN, CONTINUE INBOUND TO FLY-THROUGH. NOTE RADAR AND AIR-TO-AIR TACAN RANGES WHEN THE RADAR DETECTION IS LOST AND THEN WHEN REGAINED.]

RADAR MODE	LOST/REGAINED (L/R)	RADAR RANGE (L/R)	TACAN RANGE (L/R)

[EVALUATE THE EFFECTS OF DETECTION DROP-OUTS DURING MISSION RELATABLE INTERCEPTS.]

EFFECTS:

Card 16: Blind Ranges Data Card

2.3.13. Groundspeed/Course/ Altitude Accuracy

2.3.13.1. Purpose

The purpose of this test is to determine the accuracy with which the radar can determine the target's groundspeed, course and altitude in radar modes that provide these parameters and to assess the effect these accuracies have upon intercept tactics.

2.3.13.2. General

For radars with STT or TWS modes, the radar can usually provide target velocity over the ground (groundspeed), course over the ground (will be referred to as course) and altitude. The altitude is usually measured relative to ownship and then added to ownship altitude to get target altitude. The target's barometric altitude should be approximately the same (exactly the same given standard conditions) as the radar derived altitude as long as both the target and the test airplane have the same numbers in the Kohlsman window of their altimeters. For VS modes, only radial closure rate, is provided. This is due to the nature of the doppler rate measurement used to determine the rate. No altitude, groundspeed or course is available because range is not available to calculate the course and groundspeed or to solve the third side of the altitude triangle.

Most airplanes with modern radars are also equipped with Inertial Navigation Systems (INSs)that provide a direct display of course and groundspeed. When the target airplane and/or the test airplane are INS equipped, the INS derived course and groundspeed will be used. The barometric altitude of the target and test airplane will still have to be used. These altitudes will have to be corrected for the instrument error (a laboratory calibration) and position error (derived from flight test). The availability of this data will be assumed for both the test and target airplanes. For a test airplane or target without an INS installed, the observed airspeed, altitude, outside air temperature and externally derived winds aloft will be used to get groundspeed and course over the ground. The instrument and position error corrections for the test and target airplanes will also be required. Approximate winds aloft can be obtained from the local weather office or from Pilot Reports (PIREPs) and will probably be the greatest source of error.

2.3.13.3. Instrumentation

Data cards and an optional voice recorder will be required for this test.

2.3.13.4. Data Required

For the VS mode, closure rate accuracy portion of the test; heading, observed pressure altitude (h_{po}), observed airspeed (V_o), observed outside air temperature (OAT_o) and winds aloft are required for both the target and test airplanes. If an INS derived course and groundspeed are available in either airplane, substitute INS derived course and speed for heading, V_o, OAT_o and winds aloft. Record radar mode, bearing to the target and closure rate. For an STT or TWS mode, record heading, V_o, OAT_o, h_{po} and winds aloft for the target airplane. Record the radar mode and radar derived course, groundspeed and altitude of the target. If an INS is available in the target airplane, substitute INS derived course and groundspeed for heading, V_o, OAT_o and winds aloft.

2.3.13.6. Procedure

Following a maximum detection and maximum acquisition range test, record the target, test airplane and radar derived parameters listed above. The only radar derived parameters available during VS mode testing will be closure rate and bearing to the target. The test airplane parameters will not be needed during TWS or STT mode testing. Record the same parameters during mission relatable intercepts performed during the mission utility and integration tests (to be described). Record the data at both the low airspeeds flown in the maximum range tests (used to conserve fuel as per the flight planning section, 6.0.) and the high airspeeds flown during mission relatable intercepts. In addition, record the target altitude data during the low altitude (clutter environment) portion of the maximum detection range tests. Perform the test in the TWS, STT and VS modes.

2.3.13.7. Data Reduction and Presentation

Given the observed values for pressure altitude, airspeed and temperature; h_{po}, V_o and OAT_o, obtain the same parameters corrected for instrument errors, Δh_{pic}, ΔV_{ic} and ΔOAT_{ic} from empirically derived charts such as figure 5.

$$h_{pi}=h_{po}+\Delta h_{pic} \quad (12)$$

$$V_i=V_o+\Delta V_{ic} \quad (13)$$

$$OAT_i=OAT_o+\Delta OAT_{ic} \quad (14)$$

Obtain the aircraft position error corrections, Δh_{pos} and ΔV_{pos}, from flight test data charts such as figure 6.

$$h_{pc}=h_{pi}+\Delta h_{pos} \quad (15)$$

$$V_c=V_i+\Delta V_{pos} \quad (16)$$

Use h_{pc} and V_c to obtain M_t, the true mach number, from figure 7 and combine with OAT_i to obtain the true outside air temperature, t_a.

$$t_a=\frac{OAT_i\ (in\ absolute\ scale)}{\left[1.0+0.95\left(\frac{(\gamma-1.0)}{2.0}\right)M_t\right]} \quad (17)$$
$$\gamma=ratio\ of\ specific\ heats,\ 1.4$$

Use t_a to calculate, the local speed of sound, and combine with M_t to get the true airspeed, V_t.

$$a=\sqrt{\gamma R t_a}$$
$$\gamma=ratio\ of\ specific\ heats,\ 1.4$$
$$R=gas\ constant\ for\ air,\ 53.35\ \frac{(ft)(lb_f)}{(lb_m)(^\circ R)} \quad (18)$$
$$V_t=(M_t)(a)$$

Vectorially add the wind and heading/V_t vector to obtain the groundtrack for both airplanes. Vectorially resolve the test airplane groundtrack speed component along the bearing to the target and the target's groundtrack speed along the reciprocal bearing. Add the two to get the actual closure rate.

If INS values are available for either target, use the groundspeed and course as above to vectorially solve for the closure rate.

For TWS or STT modes, use the same procedures above to solve for the target's ground track. Use the h_{pc} for the target to compare to the radar derived data.

Compare the closure rates, groundspeeds, course and altitudes derived above to the radar derived values. The difference between the values will be the radar derived course, speed and altitude error. Relate the magnitude of the error to the utility of the radar as an aid for determining intercept parameters and tactics.

2.3.13.8. Data Cards

Sample data cards are provided as card 17.

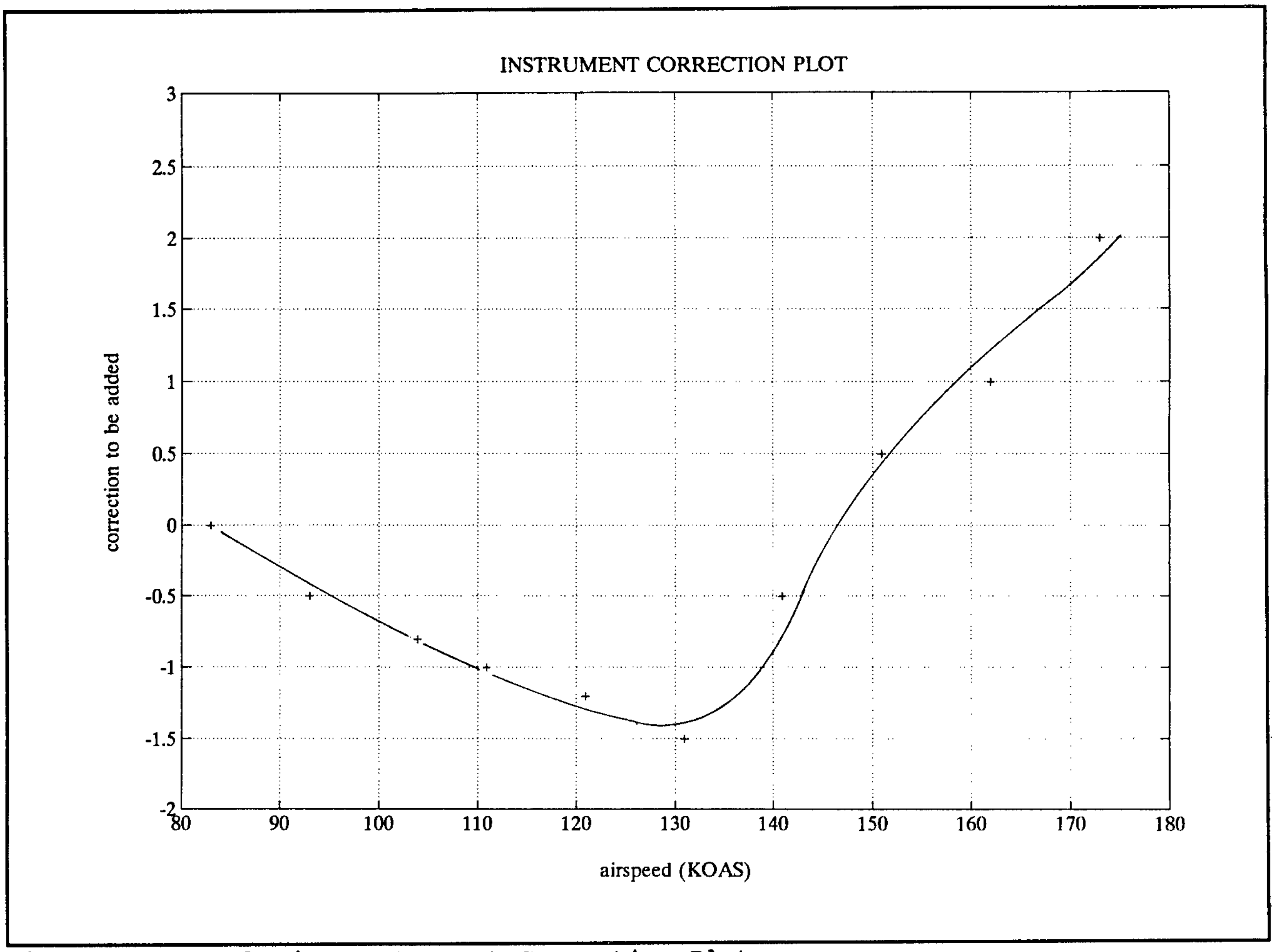


Figure 5: Sample ΔV_{ic} Instrument Correction Plot

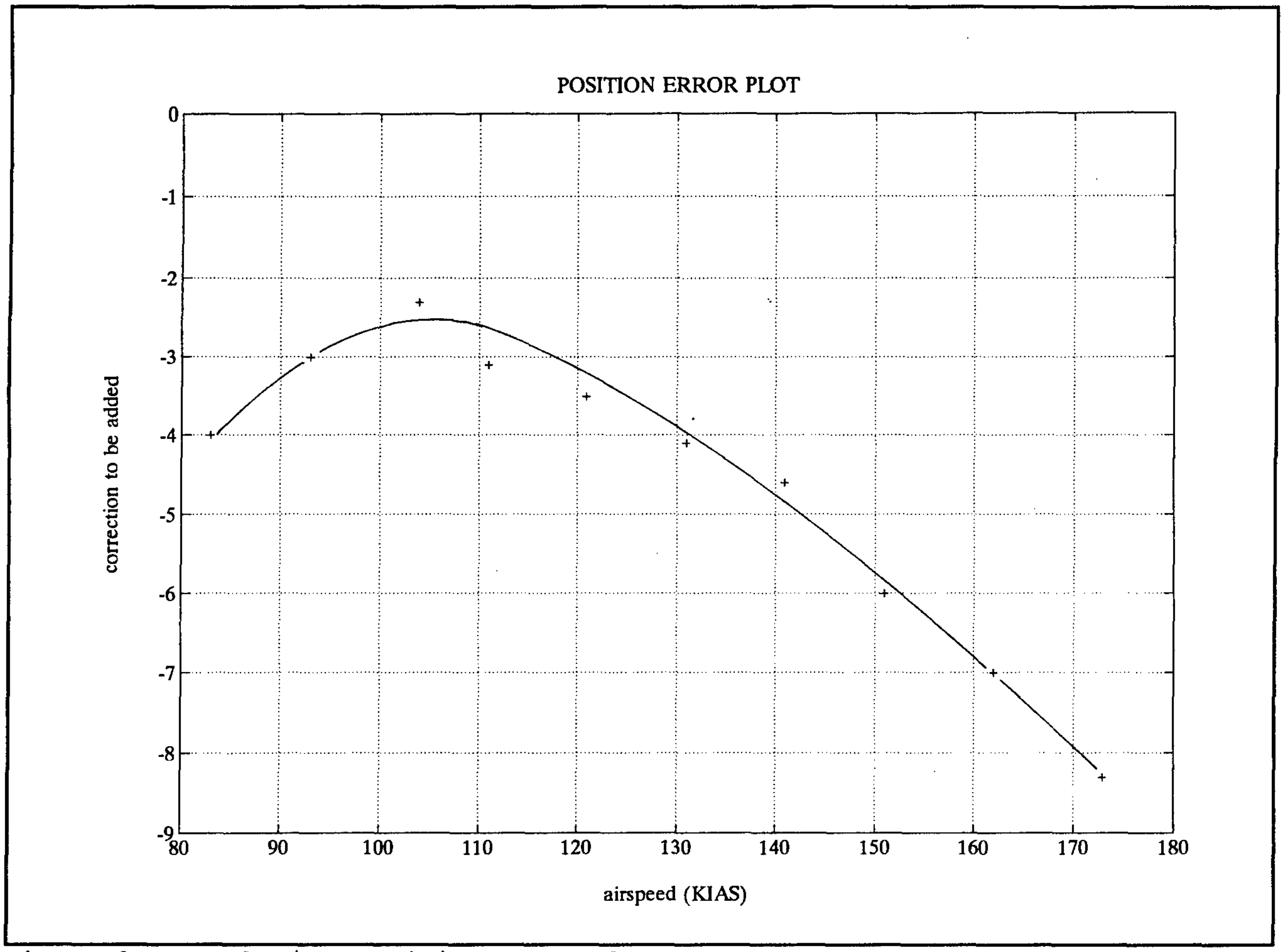


Figure 6: Sample ΔV_{pos} Position Error Plot

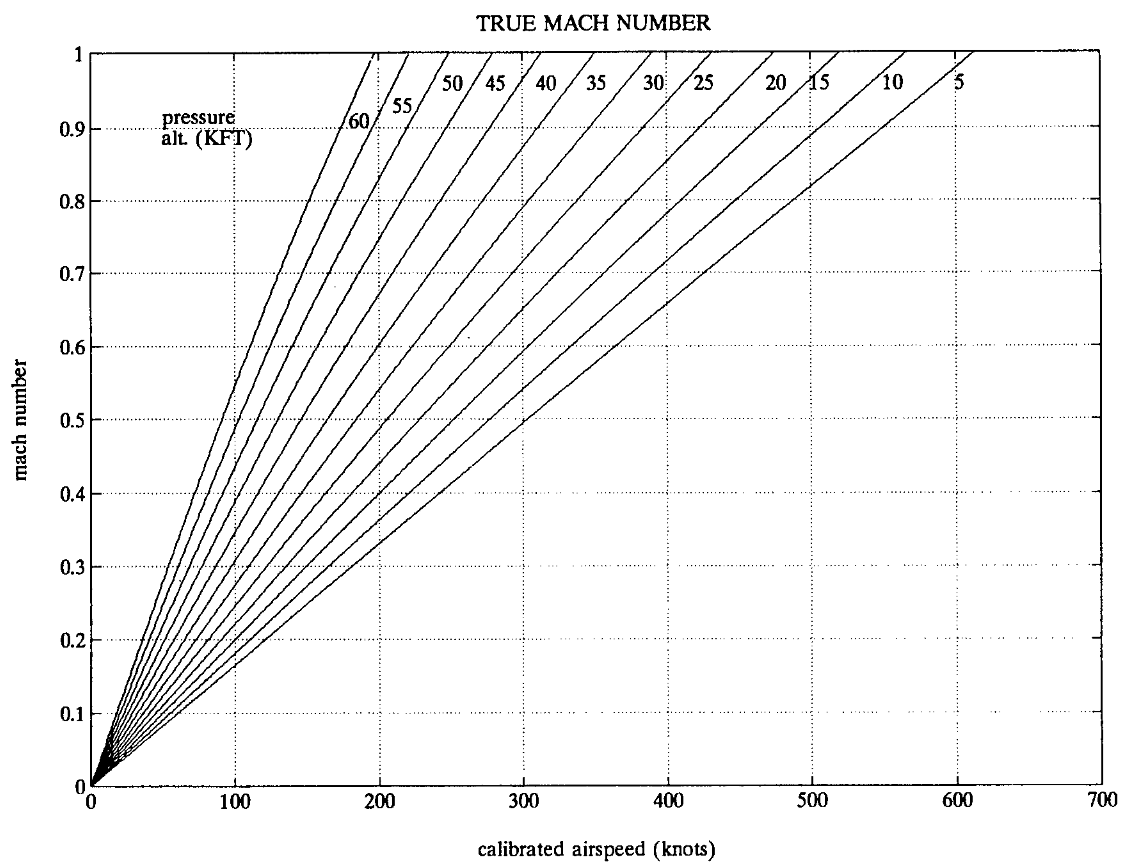


Figure 7: True Mach Number M_t From V_c and h_{pc}

CARD NUMBER ___ TIME PRIORITY L/M/H

GROUNDSPEED/COURSE/ALTITUDE ACCURACY

[FOLLOWING A MAXIMUM ACQUISITION RANGE DATA POINT, RECORD THE DATA BELOW FOR BOTH THE TEST AND TARGET AIRCRAFT. REPEAT FOR LOW AND HIGH ALTITUDE MAXIMUM RANGE TESTING. REPEAT DURING MISSION RELATABLE INTERCEPTS AND MISSION RELATABLE AIRSPEEDS. REPEAT FOR TWS, STT AND VS MODES.]

RUN #	TEST 1	TARGET 1	TEST 2	TARGET 2
MODE				
HEADING				
h_{po}				
V_o				
OAT_o				
WINDS ALOFT				

Card 17: Groundspeed/Course/Altitude Data Cards

GROUNDSPEED/COURSE/ALTITUDE ACCURACY

RUN #	TEST 1	TARGET 1	TEST 2	TARGET 2
RADAR COURSE/BEARING				
RADAR GROUNDSPEED/ CLOSURE RATE				
RADAR ALTITUDE				

[DURING MISSION RELATABLE INTERCEPTS, NOTE THE EFFECTS OF THE TARGET'S COURSE, GROUNDSPEED AND ALTITUDE ACCURACY UPON INTERCEPT TACTICS.]

EFFECTS:

Card 17: Groundspeed/Course/Altitude Data Cards (Continued)

2.3.14. Velocity Resolution

2.3.14.1. Purpose

The purpose of this test is to determine the minimum resolvable velocity difference between two targets in the VS radar mode and to assess the effects that this resolution has upon tactics.

2.3.14.2. General

The VS modes determine target bearing and closure rate, therefore, to resolve two targets, the radar must be able to detect the difference between the targets' azimuths or the targets' closure rates. The azimuth resolution was determined during the range and azimuth resolution tests. In a VS mode, while the targets are closer in azimuth than the azimuth resolution limit, they will only become distinct as two targets if they differ in speed by the velocity resolution limit. As with the previously discussed resolution tests, velocity resolution is important as a tool for raid counting and assigning the correct number of assets to the appropriate groups of targets or "cells".

2.3.14.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.3.14.4. Data Required

Record both targets' heading, h_{po}, V_o, OAT_o and winds aloft as well as the radar bearing to the target when the two targets just become resolvable as two separate targets on the VS display.

2.3.14.5. Procedure

Perform the out of clutter (high/medium altitude) maximum detection range test using the VS mode with both targets aligned along the same bearing from the test airplane and in a 300 feet trail formation at the same airspeed. After solid detection, call for the trail airplane to decelerate at approximately 1 knot per second while the lead airplane maintains a constant airspeed and both airplanes remain aligned along the bearing to the test airplane. The alignment can be set up and easily maintained by flying the same TACAN radial. If the trail target loses visual contact with the lead, have him climb 1,000 feet above the lead for safety purposes. When the test airplane is able to break the trail airplane out on the display, the test airplane should call a mark on the radio and the data either passed to the test airplane or recorded internal to the target airplane. If radio calls are used, record the trail airplane's data first since his or her airspeed may not be completely stabilized and may change before it can be recorded. The winds aloft can be obtained by the methods outlined in the groundspeed/course/altitude accuracy tests.

2.3.14.6. Data Analysis and Presentation

Use the procedure outlined in the groundspeed/course/altitude accuracy tests to determine the groundspeed components along the line of bearing between the targets and test airplane for both the targets at the time they are resolved. The difference between the two groundspeeds is the minimum resolvable closure rate difference. Relate this resolution to the effect it will have upon raid count and the optimum assignment of fighters to inbound cells.

2.3.14.7. Data Cards

A sample data card is presented as card 18.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

VELOCITY RESOLUTION

[PERFORM A MAXIMUM DETECTION RANGE TEST IN THE VS MODE WITH THE TARGETS LINED UP ON THE SAME TACAN RADIAL THAT THE TEST AIRPLANE IS FLYING. AFTER OBTAINING SOLID DETECTION, HAVE THE TRAIL AIRPLANE SLOW AT 1 KNOT PER SECOND. IF VISUAL CONTACT IS LOST BETWEEN THE TARGETS HAVE THE TRAIL TARGET CLIMB 1,000 FEET. CALL A MARK AT THE TARGET BREAK OUT AND RECORD DATA CALLS FIRST FROM THE TRAIL, THEN THE LEAD AIRPLANES.]

BEARING TO THE TARGET:

	HEADING	h_{po}	V_o	OAT_o	WINDS ALOFT
LEAD					
TRAIL					

[EVALUATE THE EFFECTS OF THE VELOCITY RESOLUTION UPON TACTICS DURING MISSION RELATABLE INTERCEPTS.]

EFFECTS:

Card 18: Velocity Resolution Data Card

2.3.15. Blind Speeds

2.3.15.1. Purpose

The purpose of this test is to determine at which closure rates that the radar is blind and to assess the effects that these blind closure rates have upon intercept tactics.

2.3.15.2. General

As described in the radar theory section the radar must be pulsed, even in the VS mode, to allow the same antenna to be used for both transmit and receive. A side effect of the pulsing process is that the velocity spectrum repeats itself at intervals related to the PRF and so the doppler shift becomes ambiguous at some regular interval. The radial velocity at which the radar is blinded by clutter is repeated at some regular interval. Several techniques, such as PRF stagger and choosing the correct PRF can ease the problem considerably, however a check should be made to see if the blind closure rates encountered are tactically significant. The technique is very similar to the blind range test described earlier.

2.3.15.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.3.15.4. Data Required

Record the test airplane and the target's heading, h_{po}, V_o, OAT_o and winds aloft before the test begins. During the turn, record the target headings and radar derived bearing when detection is lost or regained.

2.3.15.5. Procedure

Perform a maximum detection range test using the VS mode. After solid detection is obtained, record the parameters listed above and then call for the target to begin a level constant speed turn. The turn should begin before the target closes to inside 40 nm as shown on the air-to-air TACAN. The turn should be at 15° angle of bank. For radars that display pure closure rate, as the turn continues, the VS closure rate should reduce to 0, take misses as the closure rate changes to an opening rate, and then regain detection as the closure rate returns on the other side of the turn. The angle to the target will vary through the target turn radius. For radars that display closure rate with the test airplane's component of closure rate subtracted, the target will disappear as the target passes the heading perpendicular to the test airplane's flight path and then should regain detection after another 180° of turn.

During the turn, the target should call headings passed every 10° (5° if possible) over the radio. The test airplane should monitor the VS display for target misses, recording the called headings and radar derived bearings at which detection is lost and then regained, particularly in times of detection holes of several sweeps. These areas should be qualitatively evaluated for their duration and severity. If problems are noted during this test, a second run should be performed to confirm the results and to ensure that the holes were not caused by transient detection losses. During mission relatable intercepts in the VS mode, the blind closure rates should be qualitatively assessed for their effects upon tactics.

Repeat the test in each PD search mode. The target may be lost at any time in the turn during the PD test. If blind speeds are noted, the test should be repeated to ensure the drop-outs are due to blind speeds and not to other detection drops.

2.3.15.6. Data Analysis and Presentation

The procedure used in the target groundspeed accuracy test should be used to determine the test airplane and target's groundspeed before the turns began. At the headings where detection was lost or gained, the closure rate should be calculated as outlined in the groundspeed accuracy test. If problems were noted on the first test and the test was repeated, the results should be compared by plotting detection presence (1 or 0) versus the closure rates for the different runs. A consistent overlap indicates a true blind closure rate vice spurious misses. If a poor detection level occurs at a repeatable closure rate band or if the detection level is generally poor during the maneuvers compared to the constant closure rate inbound run, this should be noted. Relate the number and size of the empty and poor detection bands that are repeatable over more than one run to the possibility of a target using these blind closure rates to perform its own intercept upon the test airplane while being undetected. Relate the presence of generally poor detection levels for a target passing through a number of closure rates to the poor detection level that will occur as a target closes on the defended point while the test airplane is off the direct threat axis.

2.3.15.7. Data Cards

Sample data cards are provided as card 19.

CARD NUMBER ___ TIME ____ PRIORITY

L/M/H

BLIND SPEEDS

[PERFORM A MAXIMUM DETECTION RANGE TEST.

RECORD THE WINGS LEVEL DATA.]

RADAR MODE _______________

	h_{po}	V_o	OAT_o	WINDS ALOFT	BEARING
TEST					
TARGET					

[BEFORE 40 NM SEPARATION ON THE AIR-TO-AIR TACAN, HAVE THE TARGET BEGIN A 15° ANGLE OF BANK, CONSTANT SPEED TURN. HAVE THE TARGET CALL ITS HEADING PASSED EVERY 10°. RECORD THE CALLED HEADINGS AND RADAR BEARINGS FOR LOSS/REGAIN OF DETECTION OR BEGINNING/END OF THE POOR DETECTION LEVEL AREAS. IF PROBLEMS ARE NOTED, REPEAT THE TEST ON ANOTHER CARD. REPEAT THE ENTIRE TEST FOR EACH VS AND PD SEARCH MODE.]

Card 19: Blind Speeds Data Cards

BLIND SPEEDS

LOST/GAINED (L/G)	HEADING CALLED	RADAR BEARING

[DURING MISSION RELATABLE INTERCEPTS, RECORD QUALITATIVE COMMENTS CONCERNING THE EFFECTS OF THE BLIND SPEEDS UPON INTERCEPT TACTICS.]

EFFECTS:

Card 19: Blind Speeds Data Cards (Continued)

2.3.16. Air Combat Modes

2.3.16.1. Purpose

The purpose of this test is to evaluate the utility of the radar ACM modes as an aid to acquire and track close range maneuvering targets.

2.3.16.2. General

The nature of the ACM modes requires that they perform in situations where both the target and test airplanes are maneuvering at their absolute limit and in every conceivable range of g, crossing rate, extreme clutter etc., since it will be the goal of the target to use these limits to prevent an ACM acquisition. These absolute limits are beyond the scope of our test since they require extensive instrumentation to document problems, telemetry to ensure safety limits are not exceeded and more fuel and time than we can spare for our quick qualitative assessment. We will look at a few mission relatable situations and qualitatively assess the results, gathering data to support the assessment. The target will fly straight and level and then in a constant, moderate g turn, while the test airplane maintains visual contact and maneuvers behind the target using rolling push-overs and pull-ups to generate moderate crossing rates, g rates and varying clutter environments to check each ACM mode. Integration is particularly important for ACM modes. A qualitative assessment of the interaction of the radar, weapons controls, airplane instruments, visual scan etc. that will be used in an ACM environment is essential.

2.3.16.3. Instrumentation

Data cards, a stop watch and an optional voice recorder are required for this test.

2.3.16.4. Data Required

Record the ACM mode used, target and test airplane g, type of maneuver performed, and time from selection to lock-up of the ACM mode selected. Qualitatively describe the clutter environment to include whether the radar is looking into water, and its associated sea state, or into land, with a description of the terrain and cultural features. Record qualitative comments concerning the utility of the ACM modes for acquiring maneuvering targets.

2.3.16.5. Procedure

Place the target on the nose of the test airplane, flying in the same direction, straight and level and 1,000 feet above the test airplane until visual contact is established. Choose a speed for the target that allows the test airplane to maneuver moderately behind the target and still maintain separation. The range to the target should be 1/2 to 5 miles, consistent with the type of ACM mode being tested. Perform a series of rolling push-overs and pull-ups, keeping the target within the radar search volume. Attempt a radar acquisition in each of the ACM modes once while looking above the horizon in a non-clutter environment and once while looking down on the target into the clutter environment. Use a stop watch to time how long it takes from the time the ACM mode is selected until lock up occurs and target data is available. Qualitatively assess the location, display format, the type of target information, the accuracy of the information provided and the location and utility of the controls for selecting the ACM mode. Place the target in a level, constant airspeed, 3g turn and repeat the test. If visual contact is lost at any time during the test, both airplanes should level off and maintain steady flight until visual contact is regained.

2.3.16.6. Data Analysis and Presentation

Relate the overall utility of the ACM modes as an aid for acquiring the target in an ACM scenario and as a source of weapons targeting data. Pay particular attention to the time required to acquire the target and relate the time to the ACM environment. Relate the integration of the ACM modes with the rest of the weapons system in the context of the intense ACM environment. Confirm that the required information is available in a timely manner and in a format usable in a combat situation.

2.3.16.7. Data Cards

A sample data card is provided as card 20.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

AIR COMBAT MANEUVERING MODES

[PLACE THE TARGET ON THE NOSE, ON THE SAME HEADING, FLYING STRAIGHT AND LEVEL, 1,000 FEET ABOVE THE TEST AIRPLANE AND AT ____ KIAS. PERFORM ROLLING PUSH-OVERS AND PULL-UPS, LOCKING THE TARGET UP IN EACH MODE, ONCE LOOKING DOWN AND ONCE LOOKING UP. NOTE THE TIME FROM SELECTION TO DATA DISPLAY.]

ACM MODE	RANGE	LOOK UP/DOWN (LU/LD)	TIME

[QUALITATIVELY ASSESS THE UTILITY OF THE ACM MODES TO ACQUIRE MANEUVERING TARGETS.]

LOCATION OF DISPLAYS AND CONTROLS:

DISPLAY FORMAT:

TYPE OF TARGET INFORMATION:

ACCURACY OF TARGET INFORMATION:

GENERAL CONTROL UTILITY:

Card 20: Air Combat Maneuvering Modes Data Card

2.3.17. False Alarm Rate

2.3.17.1. Purpose

The purpose of this test is to qualitatively assess the false alarm rate of the radar and to determine the effect these false alarms have upon detecting real targets.

2.3.17.2. General

Even Restricted airspace has corridors and minimum levels where both Interrogator Friend or Foe (IFF) (also called transponder) and non-IFF equipped traffic transit. For this reason, the procedure presented here will involve a qualitative evaluation only. False alarms are generally of short duration, often just one hit, and as such a rough count or level can be approximated by closely evaluating the coherency of the tracks from scan to scan. If doubt exists on a particular track, a few can be resolved by contacting the test area controlling agency and asking them if they hold traffic at the bearing and range in question. This is not a perfect check since ATC often is unable to detect low flying non-transponder equipped traffic. The test should be performed in and out of the clutter environment (look-up and look-down). The false alarm rate is less in most radars for look-up and if the look-up test is performed above 18,000 feet than all airplanes will be transponder equipped and ATC will be able to resolve any of the false alarms noted. Clutter generally causes the false alarm rate to be greater in the look-down case than the look-up situation.

A rigorous, quantitative evaluation of the false alarm rate requires a large range, where the location of all airborne targets can be recorded. Additionally, significant recording of the radar output is usually needed in the form of digital data and display video. Without the availability of the complete instrumentation suite, video recording of the radar display alone, can greatly enhance this test. Since the false alarms tend to appear and disappear rapidly, viewing a recorded display repeatedly allows a better accounting of the number of false alarms. The value of the airborne, qualitative assessment cannot be discounted; however, since the evaluation is greatly influenced by the airborne environment.

The false alarm rate can vary greatly over the course of a flight and from flight to flight. Due to this statistical nature of the false alarm rate, a rigorous test not only requires extensive instrumentation, as mentioned above, but also repeated tests, to establish statistical significance.

2.3.17.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.3.17.4. Data Required

Record the estimated false alarm rate (number of false alarms on any given scan) in both the look-up and look-down (clutter and non-clutter) environment for each radar mode. Record qualitative comments concerning the difficulty of detecting a legitimate target airplane in the presence of the false alarms.

2.3.17.5. Procedure

During slack periods between runs at medium altitude, set up the radar for a wide scan angle limit setting and long range scale. Elevate the antenna first to look for long range, high flying targets. Qualitatively assess the number of false alarms over a number of scans. If doubt occurs on any particular target, call the controlling agency for the test airspace and request a check of the questionable area for targets. Lower the elevation angle to a selection that allows for detection of medium range low flyers. Care should be taken not to tilt the antenna below an angle that would be used for medium range detection. Repeat the qualitative assessment over a number of scans. Repeat the series for all radar modes.

2.3.17.6. Data Analysis and Presentation

Relate the false alarm rate to the difficulty of picking a real target out of the spurious radar hits and the probability of beginning an intercept on a false target. The life of the false alarms relative to the coherency of real targets on a scan to scan basis will affect the evaluation. The evaluation should be performed taking into account the expected workload and stress during a mission relatable scenario. The effects upon target detection should be assessed during mission relatable intercepts.

2.3.17.7. Data Cards

A sample data card is presented as card 21.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

FALSE ALARM RATE

[PLACE THE RADAR IN A LONG RANGE SCALE AND WIDE SCAN ANGLE PATTERN. TILT THE ANTENNA UP SO THAT THE MINIMUM DETECTION HEIGHT IS JUST ABOVE THE CLUTTER ALTITUDE. ESTIMATE THE FALSE ALARMS PRESENT AT ANY GIVEN TIME. USE ATC TO RESOLVE CONFLICTS. TILT THE ANTENNA DOWN FOR LOW FLYER MEDIUM RANGE DETECTION AND REPEAT. ENSURE THE ANGLE IS NOT TOO LOW. REPEAT THE TEST FOR ALL MODES.]

RADAR MODE	NON-CLUTTER FALSE ALARMS	CLUTTER FALSE ALARMS

[QUALITATIVELY ASSESS THE EFFECTS THAT THE CLUTTER HAS UPON DETECTION DURING MISSION RELATABLE INTERCEPTS.]

EFFECTS:

Card 21: False Alarm Rate Data Card

2.3.18. Track File Capacity

2.3.18.1. Purpose

The purpose of this test is to determine the TWS mode track file capacity and to assess the utility of the radar as an aid for SA in a combat environment.

2.3.18.2. General

Most TWS radars have a track file capacity between five and thirty. This number can be found in the contractor documentation and then should be verified while airborne. The only truth data required is to ensure that an adequate number of targets are present within the search volume to saturate the track file. Busy airfields and airways can usually be used to fulfill this requirement. The presence of the right target load can be verified by a radio call to the test area controlling agency. A phone call before the flight can also be used to cut down on radio transmissions and to alleviate confusion as to the desired track density. Often this data point can be obtained while returning to base using the home airfield overhead traffic.

2.3.18.3. Instrumentation

Data cards and an optional voice recorder will be required for this test.

2.3.18.4. Data Required

While in the TWS mode, record the maximum number of tracks displayed during the flight. Record qualitative comments concerning the effect the maximum number of TWS tracks has upon the utility of the radar as an aid to SA in a mission relatable multiple target environment.

2.3.18.5. Procedure

Place the radar in a TWS mode, wide scan angle limit and long range scale. Turn the airplane to look over a large airport or busy airway. Check to see if the TWS mode establishes the maximum number of tracks designed to be available. If a lesser number of tracks are established, call the test area controlling agency and request a count of airplanes over the field or along the airway within the radar search volume. If enough tracks are not present, request a vector to an area with enough tracks to saturate the TWS. Throughout the flight, qualitatively evaluate the utility of the track file capacity for maintenance of air picture SA within the test area.

2.3.18.6. Data Analysis and Presentation

Relate the maximum number of TWS tracks seen at one time to the utility of the TWS mode for maintenance of battlefield SA.

2.3.18.7. Data Cards

A sample data card is presented as card 22.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

TRACK FILE CAPACITY

[TURN THE AIRPLANE TOWARDS A LARGE AIRPORT OR AIRWAY WITHIN THE SEARCH VOLUME. ESTABLISH THE TWS MODE, WIDE AZIMUTH SCAN LIMIT AND LONG RANGE SCALE. COUNT THE MAXIMUM NUMBER OF TRACKS. IF THE NUMBER OF TRACKS IS LESS THAN DESIGNED, CONTACT ATC FOR A COUNT OVER THE AIRPORT OR AIRWAY. IF NOT ENOUGH TRACKS ARE AIRBORNE, REQUEST A VECTOR TO A HIGH DENSITY AIR TRAFFIC AREA.]

DESIGNED MAXIMUM TRACK FILE CAPACITY________________________

MAXIMUM NUMBER OF TRACK FILES SEEN WHILE AIRBORNE__________

[QUALITATIVELY ASSESS THE EFFECT THE MAXIMUM NUMBER OF TRACK FILES SEEN WHILE AIRBORNE HAS UPON THE OPERATOR'S SA IN A HIGH STRESS/TARGET RICH, MISSION RELATABLE ENVIRONMENT.]

EFFECTS:

Card 22: Track File Capacity Data Card

2.3.19. Mission Utility and Integration

2.13.9.1. Purpose

The purpose of this test is to qualitatively assess the overall utility of the radar for the assigned mission and the integration and compatibility of the radar performance parameters, controls and display within the airplane.

2.3.19.2. General

The mission utility and integration test is the most important test of the series. During this test, mission relatable intercepts and attacks are performed to qualitatively assess the radar. The quantitative and qualitative assessments of the previous tests are used to support and justify the qualitative determinations made during the intercepts and attacks.

Utility refers to the overall usefulness of the radar as it is implemented, as an aid to the mission. The radar parameters must match the expected operational needs. Integration refers to the way the radar has been blended into the entire airborne system. From the evaluator's standpoint this characteristic is intimately tied into the area of human factors.

The qualitative assessments in mission relatable scenarios specifically called for in the previous tests are also performed during these intercepts and attacks. Care should be taken; however, to ensure that the evaluator does not get too involved in recording qualitative comments to the detriment of watching the progress of the intercept and evaluating the radar. A conscious effort should be made not to get too involved in looking for specifics on at least the first intercept and attack to ensure that an overall qualitative assessment can be made. A voice recorder can be used to make comments without distracting the evaluator from the display or the outbound run can be used to record results.

Multiple runs should be performed using different radar modes and mode combinations in as many different types of attacks as possible (including supersonic runs, if applicable, to assess the utility of the radar in high closure rate intercepts). The most likely scenarios should be performed first and others performed as flight time allows.

2.3.19.3. Instrumentation

Data cards are required for this test. A voice recorder is highly recommended.

2.3.19.4. Data Required

Record qualitative comments concerning the utility and integration of the radar. Record the effects of the parameters determined in previous tests during the intercepts and attacks as called for at the end of each test procedure.

2.3.19.5. Procedure

Place the target beyond the ranges found during the maximum detection range tests for the mode being used. Place the target 1,000 feet above the test airplane for the first run. Use the most likely long range intercept mode for the first run and the rest in order of priority as time allows. Use a medium to wide scan angle limit and a long range scale with a two to four bar pattern to simulate a search for an inbound threat. Call for the target to turn inbound and turn the test airplane towards the target. Use a mission relatable subsonic intercept speed for the first run (usually Mach (M) 0.85 to 0.9 for both the target and test airplane is adequate). It is important to use enough speed, since the closure rate will affect the evaluation of the detection range and update rate. Perform a normal intercept, optimizing the range scale, scan angle limits, antenna elevation angle etc. until the target is confirmed and an STT is acquired. Continue inbound and convert the intercept to an astern attack of the target as the target continues to fly straight and level. Use the ACM modes during the conversion and simulate the selection and firing of weapons, paying particular attention to the effects of the radar parameters and human factors upon the tactics used for each weapon.

On later intercepts, try the other long range detection modes for the initial detection and other possible combinations of modes while closing. In addition, perform some of the intercepts with the target at as low an altitude as safety permits, to assess the effects of the clutter environment. If two targets are available, use them both on at least one intercept and then split them onto two stations, switching from one to the other (three in a barrel) to maximize the number of intercepts during the flight. If time, fuel and airspace permit, perform one supersonic intercept using a VS mode for initial detection, paying particular attention to the effects of high closure rates. If time permits, allow the target to maneuver up to 30° and 5,000 feet (excluding 1,000 feet above or below the test airplane altitude) off of the planned track without informing the evaluator of the maneuver beforehand, to simulate a moderately "jinking" target. Record qualitative comments concerning the utility of the radar for the assigned mission, including the effects of the parameters determined during previous tests and the overall integration of the radar into the airplane.

2.3.19.6. Data Analysis and Presentation

Relate the qualitative deficiencies noted to their effects upon the performance of the intercepts and astern conversions. Note any limitations upon tactics imposed by the radar parameters, utility or integration. As an example, the radar may not be able to detect a target at a range that allows the operator to set up and fire the weapons carried at their maximum range. The radar should not be driving tactics. Use the applicable results from the previous tests to support the qualitative results.

2.3.19.7. Data Cards

A sample data card is presented as card 23.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

MISSION UTILITY AND INTEGRATION

[POSITION THE TARGET ON THE NOSE AT ___ NM AND 1,000 FEET ABOVE THE TEST AIRPLANE. TURN THE TARGET AND TEST AIRPLANE TOWARDS EACH OTHER, ACCELERATING TO M=__. USE THE ____ MODE, WIDE SCAN ANGLE LIMIT, ____BAR PATTERN, AND ____ NM RANGE SCALE. GAIN AN STT AND CONTINUE INBOUND. SIMULATE A LONG RANGE MISSILE LAUNCH, THEN A MEDIUM RANGE HEAD-ON SHOT. OFFSET THE TARGET AT 10 NM AND PERFORM AN ASTERN CONVERSION. USE THE ACM MODES DURING THE CONVERSION. SIMULATE ASTERN MISSILE AND GUN ATTACKS. MAKE NOTES CONCERNING THE MISSION UTILITY, INTEGRATION AND THE EFFECTS OF RADAR PARAMETERS. REPEAT WITH THE TARGET AT ____ FEET AGL. REPEAT THE TEST WITH THE TARGET AND TEST AIRPLANE AT M=___ AND IN THE VS MODE FOR INITIAL DETECTION.]

NOTES:

Card 23: Air-to-Air Mission Utility And Integration Data Card

2.3.20. Introduction to Advanced Air-to-Air Radar Test Techniques

As mentioned in Chapter 1, only the most rudimentary form of the air-to-air radar test techniques are presented in this book. Chapter 1 details the reasons for this format; however, in many applications, more rigor, accuracy and documentation of results are required. Table I outlines additional instrumentation and assets which are typically applied in these more advanced tests. The purpose of this table is merely to emphasize the existence of these advanced techniques. Further, this list is not exhaustive. Many innovative uses of assets and instrumentation exist. It is hoped that the examples provided leave the reader with a taste of how the test can be made more rigorous through the judicious use of instrumentation. In application; the user must refer to the more advanced documents referenced in Chapter 1 or solicit help from more experienced testers.

Table I: Additional Assets or Instrumentation for use in Advanced Air-to-Air Radar Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Preflight and Built-in-Tests.	Digital Recorder.	Typically records data from data bus on which radar passes the BIT results. Allows precise documentation of test results. Usually used in conjunction with fault insertion tests.
	Video recording of display.	Provides automatic recording of what the operator sees as a fault status is displayed.
Controls and Displays.	Video recording of display.	Allows automatic documentation of display problems as well as post-flight analysis and evaluation.
	Cockpit mock-ups, reconfigurable cockpits and virtual cockpits.	Typically used for in-depth ground tests of human factors and in iterative cockpit design.
	Digital recording of operator actions.	Can be used as a means of precisely recording operator selections to document noted problems and as a means of performing operator tasking analysis.
Scan Rate.	Digital recording of radar data.	In some systems the sweep position can be digitally recorded as output of a scan converter. In this case the instantaneous as well as the average scan rate can be calculated as required.
	Time stamped video recording of display.	Even in the absence of digital data, the instantaneous and average scan rates can be derived using appropriately time stamped video.

Table I: Additional Assets or Instrumentation for use in Advanced Air-to-Air Radar Tests (Continued)

Test	Additional Asset or Instrumentation	Purpose/Benefit
Scan Angle Limits.	Digital Recording of aircraft heading and position for both the target and test aircraft, time stamped video recording of display.	The test can be made more accurate by recording the precise target and test aircraft location, precise test aircraft heading (these parameters are either derived and recorded on-board or using a space positioning range as appropriate) as well as precise time. The radar display is video recorded and time stamped and as the target disappears, the exact angle off boresight can be calculated based upon geometric calculations.
Elevation Angle Limits.	Similar to scan angle limits except vertical angles are recorded vice headings.	Similar to scan angle limits except the vertical angles to the target are calculated vice the horizontal angles.
Tracking Rate limits.	Digital recording of test and target airplane positions, test airplane heading and turning rate, radar data including STT positions and track files and time stamp.	The test and target airplane positions and the test airplane turning rate (may be derived using onboard or range space positioning data) are geometrically reduced to derive the crossing rate of the target at the time that the radar data indicates that the radar has lost track.
Antenna Stabilization Limits.	Digital recording of test aircraft time stamped roll, pitch and yaw rates and time stamped video recording of the display.	The direct measurement of the roll, pitch and yaw rates are correlated to degradation on the time stamped display.
Range and Bearing Accuracy.	Digital recording of time stamped test and target aircraft position and time stamped radar display video or digital radar track files with radar derived bearing and range to target.	Target and test aircraft location from either onboard instrumentation or range space positioning data are used to calculate the actual range and bearing to the target at the time a range and bearing is derived using the radar. The video recorded range and bearing are compared directly and may in turn be compared to the range and bearing within the radar track file.
Range and Bearing Resolution.	Precise control of target locations is provided by an instrumented range. Digital recording of time stamped target and test aircraft location. Video recording of the radar display.	Precise control of the targets can help prevent range contamination of the bearing resolution data point. The resolutions can be directly determined by geometrically comparing the positions of the targets and the test airplane at the time breakout occurs.

Table I: Additional Assets or Instrumentation for use in Advanced Air-to-Air Radar Tests (Continued)

Test	Additional Asset or Instrumentation	Purpose/Benefit
Maximum Detection Range.	Digital recording of time stamped radar detections. Video recording of time stamped radar display. Time stamped test and target aircraft locations. Propagation prediction assets. Real time measurement of casual interference.	The test and target aircraft locations are geometrically reduced to provide actual, time stamped locations of the target in radar space. This information is used to validate hits and misses at corresponding bearings and ranges on the target as recorded on the radar display and digitally recorded radar detection data. Often, the real time propagation performance is predicted on instrumented ranges for the frequency of the test radar and casual interference is recorded on the aircraft using special instrumentation. Sometimes this information is already designed into the test radar and needs only to be recorded.
Maximum Unambiguous Range.	Video recording of time stamped radar display. Time stamped test and target aircraft locations.	The geometrically reduced test and target locations are used to verify the displayed range to the target after detection.
Maximum Acquisition Range.	Same as Maximum Detection Range with the addition of track file data and operator selection of STT.	Range to the target is geometrically derived from the time stamped space positioning data when the recorded video shows that the operator has successfully been able to acquire the target.
Blind Ranges.	Same as Maximum Detection Range test.	Reduction similar to Maximum Detection Range Test with data plots the same as in the test described in this book. Emphasis is placed upon the statistical significance and repeatability of the blind ranges.
Groundspeed /Course /Altitude Accuracy.	Digital recording of time stamped target aircraft location, groundspeed, course and altitude. Video recording of the time stamped radar display.	Internally recorded or range derived target parameters are time correlated to the displayed radar information.
Velocity Resolution.	Digital recording of time stamped target aircraft groundspeed. Video recording of the time stamped radar display.	Internally recorded or range derived target groundspeeds are time correlated to the displayed radar information at breakout.

Table I: Additional Assets or Instrumentation for use in Advanced Air-to-Air Radar Tests (Continued)

Test	Additional Asset or Instrumentation	Purpose/Benefit
Blind Speeds.	Digital recording of precise time stamped target and test aircraft heading and groundspeed. Video recording of the time stamped radar display.	High accuracy as well as high update and recording rates are necessary to get accurate target closure rates during maneuvers. Can be derived onboard or on a space positioning range. Time correlated target and test aircraft parameters are compared to the geometrically derived closure rate. This is compared to drop-outs in the radar display. Emphasis is placed upon the statistical significance and repeatability of the blind speeds.
Air Combat Modes.	Digital recording of precise, time stamped test and target aircraft positions, rates and accelerations; digital recording of time stamped radar data, time stamped video recording of the radar and head up display.	For complete documentation, this test requires precise documentation of all target and test aircraft dynamics and locations, which are then time correlated with radar data and the operator displays.
False Alarm Rate.	Ground radar coverage and time stamped recording of the entire radar search volume. Time stamped video recording of the radar display. Digital recording of time stamped radar detection data.	Radar detection data are time correlated with the ground radar detection data to verify or disprove the existence of actual radar targets.
Track File Capacity.	Video recording of the radar display.	Since the test simply verifies the maximum track file number, the recording of the radar display provides some added documentation.
Mission Utility and Integration.	Digital recording of precise, time stamped test and target aircraft positions, rates and accelerations; digital recording of time stamped radar data; time stamped video recording of radar and head up display.	This test requires the largest amount of data to completely document the results. It is during this test that most of the unexpected problems are found. In anticipation of having to document these deficiencies, maximum instrumentation and range support are sometimes brought to bear in case unforseen data are required in post-flight analysis.

2.4. AIR-TO-GROUND RADAR TEST TECHNIQUES

2.4.1. Scan Rate

2.4.1.1. Purpose

The purpose of this test is to determine the average radar scan rate and its effect upon the utility of the radar presentation.

2.4.1.2. General

Most air-to-ground radars operate in a single bar, raster scan format. The rate at which the antenna moves from side to side determines the scan rate. Since the antenna must stop at each side and since the moving parts have some inertia, the actual scan rate varies through the scan and as the scan angle limits are changed. The important characteristic for the air-to-ground radar is how often the target and the map display is updated and so an average scan rate over a number of scans in each scan angle limit setting will be used.[7]

Scan rate can affect several radar performance factors. A quick scan rate is desired to provide a rapid update of the target position and the radar navigation display. If the update is too slow, the airplane's position on the radar map presentation will change between scans requiring mental integration. In addition, during very low level flying, the radar presentation may change drastically between scans. A very rapid display update alleviates these problems. The update rate must also be rapid enough to provide quick and accurate position updates of the target during the final seconds of the attack. This requirement will vary depending upon the accuracy of the navigation system used (drift), the accuracy requirements of the weapons used, and the accuracy with which the radar can designate a target at longer ranges. Unfortunately, there are limits to the scan rate that can be used. The limiting factor is usually the number of radar hits required to build a consistent radar display. Too few hits results in an inconsistent and washed out display. Once the requirement for adequate mapping quality is obtained, the scan rate should be left at the highest possible rate to update the display as frequently as possible. Mapping quality and consistency tests will be discussed later.

2.4.1.3. Instrumentation

A stop watch and data cards are required for this test. A voice recorder is optional.

2.4.1.4. Data Required

Measure the time for ten complete radar scans (one side to the other and back) at each scan angle limit setting. Record qualitative comments concerning the effects of the display update rate upon the mapping display utility and the target display during mission relatable attacks.

2.4.1.5. Procedure

While on the ground, use a stop watch to measure the time for the sweep to move from one side of the display and back for ten full sweeps. Perform the test at all scan angle limit settings and repeat for one setting while airborne to confirm the ground test. If a discrepancy occurs between the ground and airborne data, repeat for all scan angle limits. While performing attacks at mission relatable speeds, evaluate the effect the update rate has upon the utility of the display for radar navigation. During the final phases of the attack, note the effect the update rate has upon the operator's ability to accurately maintain the designator or cursors over the target position.

2.4.1.6. Data Analysis and Presentation

The scan rate is calculated using the following relationship:

$$\text{Scan Rate} = \frac{(\text{Scan Angle Limit in deg})(20)}{(\text{Time for 10 Sweeps})} \tag{19}$$

The mapping quality and consistency test to be discussed later will evaluate whether the scan rate is slow enough to provide a consistent mapping display. The test discussed in this section is designed to evaluate whether the rate is quick enough to provide an update rate of the display adequate for all mission relatable scan angle limit selections and attack profiles. Relate the update rate to the necessity for near real-time

[7] In the context used here, the scan rate and update rate are the same.

navigation and target positioning data during high speed, low level ingress to the target when the radar horizon is very short and to the necessity to perform terminal target updates before delivering ordnance.

2.4.1.7. Data Cards

A sample data card is presented as card 24.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND SCAN RATE

[RECORD TIME FOR 10 COMPLETE SCANS.]

RADAR MODE	SCAN ANGLE LIMIT	TIME FOR 10 SWEEPS

[RECORD QUALITATIVE COMMENTS ON THE MAP UPDATE RATE AND TARGET POSITION UPDATE RATE.]

TEST AIRPLANE SPEED____

TEST AIRPLANE ALTITUDE_____

SCAN ANGLE LIMIT____

RADAR MODE_____________________

TYPE ATTACK FLOWN_____________________

EFFECTS:

Card 24: Air-to-Ground Scan Rate Data Card

2.4.2. Scan Angle Limits

2.4.2.1. Purpose

The purpose of this test is to determine the scan angle limits of the radar and their effects upon the utility of the radar search volume.

2.4.2.2. General

Most air-to-ground radars operate in a single bar, raster scan format and often have several operator selectable antenna scan angle limits. The largest selection is usually bounded by the physical scan angle limits of the antenna. The bounds are often set by the physical limits of the antenna against the nose cone faring covering the antenna or even by line of sight interference between the radar beam and airplane structures. In addition, when extremely wide limits are used, the time that the antenna can spend at any specific bearing within the search volume is reduced for a given display update rate. When a lower scan angle limit selection is made in order to concentrate the search volume, the operator is often able to slew the center of the search volume within these maximum left and right limits. For these reasons, the maximum scan angle limits become critical and should be measured.

The maximum limits should be evaluated while performing radar navigation to ensure enough area is displayed to allow orientation on a tactical chart and during searches for targets of opportunity to ensure enough volume is searched such that the radar does not limit the airplane in its area of attack. During attacks, the maximum angle off the nose to the target expected in mission relatable tactics must be used to evaluate the scan angle limits while using the smaller angle selections. The smaller selections are used after the initial position of the target is determined to allow concentrating the radar on the target area and the intended flight path. The range and number of selections must be suitable for the expected scenarios for which the airplane is designed to operate.

2.4.2.3. Instrumentation

Data cards are required for this test with an optional voice recorder.

2.4.2.4. Data Required

Record the heading of the test airplane with a target of opportunity over the nose and just at the edge of the display for each scan angle setting for both the left and right limit. Record qualitative comments concerning the utility of the maximum scan angle limit and the smaller angle selections.

2.4.2.5. Procedure

Choose a target of opportunity at least 15 nm ahead of the test airplane to allow the test turn to be completed without significantly affecting the geometry of the target. If the display is truncated at the scan angle limit selected, the range must be inside of the truncated area. Place the target just to the right or left of the nose of the test airplane with the sweep centered on the nose. Turn the test airplane slowly toward the target, marking the test airplane heading as the nose crosses the target bearing and as the target passes off of the radar display. Repeat to the other side and for all scan angle limit selections. Qualitatively evaluate the effect of the maximum scan angle limit upon the utility of the radar map display for orientation on a tactical map, for the radar's utility in finding targets of opportunity over a wide area and for any constraints that the limit may pose upon attack tactics by restricting the maximum angle off of the nose during ingress to the target. Assess the utility of the smaller angle limits for concentrating the radar on a narrower area as the target position and the flight path to it are narrowed.

2.4.2.6. Data Analysis and Presentation

Subtract the test airplane heading while the target is over the test airplane nose from the heading as contact is lost for the left/right at each scan angle limit setting to determine the measured scan angle limits. Use the measured limits as supporting data where deficiencies are noted in the qualitative evaluation of the scan angle limits. Relate problems noted with the maximum scan angle limits to the utility of the map display for area orientation, finding targets of opportunity and to the limitations imposed upon inbound tactics by the maximum angle off the nose to the target that can be used while still illuminating the target. Relate the number and limits of the smaller angle selections to the desirability of narrowing the scan volume as the target position is refined.

2.4.2.7. Data Cards

A sample data card is presented as card 25.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND SCAN ANGLE LIMITS

[CHOOSE A TARGET OF OPPORTUNITY JUST TO THE LEFT OR RIGHT OF THE NOSE AT 15 NM. TURN TOWARDS THE TARGET. RECORD THE TEST A/C HEADING AS THE TARGET PASSES THROUGH THE NOSE AND WHEN IT IS LOST FROM THE DISPLAY DURING THE TEST AIRPLANE TURN. REPEAT TO THE OTHER SIDE AND FOR EACH SCAN ANGLE LIMIT SELECTION.]

RADAR MODE	AZ LIMIT SELECTION	NOSE	LEFT/RIGHT (L/R)	LOST TARGET

[RECORD QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE MAXIMUM SCAN ANGLE FOR RADAR MAPPING AND ORIENTATION, ITS EFFECT UPON TACTICS (MAXIMUM ANGLE OFF OF TARGET) AND FINDING TARGETS OF OPPORTUNITY. RECORD COMMENTS ON THE UTILITY OF THE RANGE AND NUMBER OF THE SMALLER SELECTIONS.]

SCAN ANGLE LIMIT SELECTION_____

TARGET RELATIVE BEARING_____

TYPE OF ATTACK________________________

EFFECTS:

Card 25: Air-to-Ground Scan Angle Limits Data Card

2.4.3. Elevation Angle Limits

2.4.3.1. Purpose

The purpose of this test is to determine the elevation angle limits of the radar antenna and their effects upon the utility of the radar search volume.

2.4.3.2. General

As with scan angle limits, the elevation angle limits of the radar are often established by the physical limits that the antenna can be slewed up or down. These limits can be physical, caused by space or gimbal constraints within the nose cone or by interference between the radar beam and the airplane structure, although the latter is less likely for the elevation limits than for the azimuth limits. Elevation angle limits are important to air-to-ground radars since they limit the maximum pitch maneuvers the test airplane can perform and still maintain radar contact with the target. The airplane must be able to maneuver as much as possible in the terminal attack phase to defeat surface defenses while at the same time prosecuting the attack. In addition, many weapon deliveries require pitching maneuvers. Finally, the lower limit will affect the minimum range that the airplane can close on the target without losing radar contact. Most modern radar antennas have a gimbal limit of approximately 60° above and below the airplane centerline (the exact centerline used varies from airplane to airplane as with the air-to-air platforms). The limits should be measured and then the effects of these limits should be evaluated during mission relatable simulated or actual weapons deliveries, choosing the deliveries with the largest variations in pitch for the evaluation. Mission relatable evasive maneuvering (jinking) should also be performed inbound to the target.

2.4.3.3. Instrumentation

Data cards are required for this test with an optional voice recorder.

2.4.3.4. Data Required

Record the antenna elevation angle displayed on the radar display as radar video is lost in the vicinity of the cursors designating the center of the radar scan volume.

2.4.3.5. Procedure

Begin the test at a medium altitude, 15,000 feet AGL or above is typical, with enough airspeed to perform a slow pitch up to the expected theoretical elevation angle limits and to perform a recovery to level flight. Choose a target of opportunity on the nose of the airplane at least 20 nm away. Designate the target for geostable tracking using the cursor designator, if the radar is capable, narrowing the scan angle limits to a narrow selection. If the radar does not automatically select the range scale, select a scale that just includes the target. Perform a slow pitch up until the radar display disappears over the target area or until tracking breaks lock. Record the antenna elevation at the time. Re-establish target tracking and slow the test airplane. Begin a pitch over, looking for the same indications as above. Discontinue the test if any aircraft limits are reached and insure enough altitude is available for the test aircraft to perform a safe recovery from the nose-down attitude. Consult all available aircraft performance data before attempting the maneuver. Record the antenna elevation as above. During mission relatable attacks, record the effects the above antenna elevation limits have upon ingress and weapon delivery tactics.

2.4.3.6. Data Analysis and Presentation

Use the displayed antenna elevation at the time that radar detection is lost on the target of opportunity as the elevation limits. Relate the elevation limits to the restrictions that they place upon jinking and upon delivery tactics while maintaining target radar detection.

2.4.3.7. Data Cards

A sample data card is presented as card 26.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND ELEVATION ANGLE LIMITS

[CLIMB TO ________ FEET AGL, INCREASE SPEED TO ___ KIAS AND CHOOSE A TARGET OF OPPORTUNITY ON THE NOSE AT 20 NM. DESIGNATE THE TARGET USING GEOSTABLE CURSORS AND NARROW THE DISPLAY. SELECT THE SHORTEST POSSIBLE RANGE SCALE WHICH STILL DISPLAYS THE TARGET. PITCH UP UNTIL THE TARGET IS NOT DETECTED AND RECORD THE ANTENNA ANGLE. SLOW TO ___ KIAS AND REPEAT IN A PUSH OVER.]

LOWER LIMIT	UPPER LIMIT

[QUALITATIVELY EVALUATE THE EFFECTS OF THE ELEVATION LIMITS UPON INGRESS TACTICS AND WEAPON DELIVERIES.]

TACTIC OR DELIVERY____

MANEUVER____

EFFECTS:

Card 26: Air-to-Ground Elevation Angle Limits Data Card

2.4.4 Antenna Stabilization Limits

2.4.4.1. Purpose

The purpose of this test is to evaluate the ability of the radar antenna to maintain stabilization during maneuvering flight and to determine its effects upon ingress and weapon delivery tactics.

2.4.4.2. General

As discussed in the radar theory section, many radar antennas are gyroscopically or inertially stabilized in relation to the horizon within the boundaries of the scan and elevation limits; however, there are rate limitations to which the airplane can be maneuvered before this stabilization is degraded. The radar should be designed such that these boundaries are beyond the maneuvering limits of the host airplane for all three maneuvering axes (roll, pitch and yaw). Measuring yaw rates in flight without instrumentation is quite difficult, step inputs to the maximum allowable at a mission relatable maneuvering speed will be used instead of an actual yaw rate measurement. The loss of stabilization usually manifests itself as a degradation of mapping and detection, strobing and other perturbations of the general radar display. The minimum criteria is whether the display is still adequate for radar navigation and area orientation, as well as target detection and accurate target designation. Combined roll, pitch and yaw maneuvers can have their own effects upon the display and as such should also be evaluated.

2.4.4.3. Instrumentation

Data cards and a stop watch are required for the test with an optional voice recorder.

2.4.4.4. Data Required

Record the time to go from 40° nose low to 40° nose high at a constant g rate up to the g limit of the airplane. Record the time to roll 360° at increasing stick deflections. Record the percent of rudder throw used to achieve increasing yaw rates. During all maneuvers, make qualitative comments on the effects that the maneuvers have upon the radar display and detection performance. Record the same qualitative comments during rolling push-overs and pull-ups. Record qualitative comments concerning the effects of the antenna stabilization limits (if any are found) during mission relatable ingress evasive maneuvers and while performing mission relatable weapon deliveries.

2.4.4.6. Procedure

Climb to a medium altitude (approximately 15,000 feet AGL is typical) and set an airspeed that allows for safe, high g maneuvers (usually 300 to 400 KIAS is adequate). Establish a normal search or radar mapping mode. Select a scan angle limit at approximately 30° to 40° and set the antenna elevation to optimize the display around a point 30 to 40 nm ahead of the airplane. Center the display on the nose. Maneuver to 50° nose low and establish a 2g pull-up to 50° nose high at a constant 2g rate. Mark the time while passing from 40° nose low to 40° nose high. Note any degradation in the radar display, including any loss of detection at any ranges that were present before maneuvering, strobing or spoking on the display or any other effects. If the elevation angle limits are less than 50°, then a smaller maneuver will have to be performed to maintain contact with the target. Repeat the test at increasing g levels until degradation is noted or the g limit of the airplane is reached.

Center the scan volume 20° off of the nose. Roll the airplane 360° at 1/4 stick deflection, noting the time to complete the roll and any degradation in detection or the display. Repeat at 1/2, 3/4 and full stick deflection if the airplane limits allow. With the scan volume again centered on the nose, perform a step input of the rudder at 1/4 deflection. Note any degradation of detection or the display. Repeat at 1/2, 3/4 and full rudder deflections if the aircraft limits allow. If no degradation is noted while performing the tests above, perform a series of rolling push-overs and pull-ups at increasing g rates until the limits of the airplane are reached. Again, look for degradation in detection or the radar display. During ingress evasive maneuvers and weapon delivery maneuvers, note the effects upon tactics of the limits found above.

2.4.4.7. Data Analysis and Presentation

Divide the time to perform the pitch up maneuvers into the 80° covered to obtain the average pitch rate. Divide the time to roll into 360° to get the average roll rate. If no degradation is noted within the maneuvering limits of the airplane during single axis or the multiple axis maneuvers, then the stabilization limits are probably satisfactory. If degradation is noted, it should be related to the limits that this degradation imposes upon tactics. The amount of limitation depends upon the axis involved (a pitch axis limit of 2g on an 8g airplane would be more serious than a yaw axis limit of 1/4 rudder deflection) and the level at which the degradation is noted. These limitations should be verified during mission relatable attacks.

2.4.4.8. Data Cards

Sample data cards are provided as card 27.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND ANTENNA STABILIZATION LIMITS

[CLIMB TO _____ FEET AGL, SET ___KIAS AND SELECT A SEARCH OR MAPPING MODE AND A 30° TO 40° AZIMUTH LIMIT. OPTIMIZE THE ANTENNA ELEVATION FOR A 30 TO 40 NM RANGE MAP DISPLAY AND SELECT A RANGE SCALE TO COVER ALL THE RADAR VIDEO PROVIDED. PITCH DOWN TO 50° LOW AND PULL-UP AT 2G TO 50° NOSE HIGH. TIME 40° LOW TO 40° HIGH. NOTE ANY DEGRADATION. REPEAT AT INCREASING G RATES.]

TIME TO PITCH	G	DEGRADATION

[CENTER THE SCAN VOLUME 20° OFF OF THE NOSE. ROLL THE AIRCRAFT AT 1/4 STICK DEFLECTION. NOTE THE TIME TO ROLL 360° AND DEGRADATION. REPEAT AT 1/2, 3/4, AND FULL DEFLECTION.]

TIME TO ROLL	G	DEGRADATION

Card 27: Air-to-Ground Antenna Stabilization Limits Data Cards

AIR-TO-GROUND ANTENNA STABILIZATION LIMITS

[CENTER THE SCAN VOLUME ON THE NOSE. PROVIDE A STEP INPUT OF RUDDER AT 1/4 DEFLECTION. NOTE DEGRADATION AND REPEAT AT 1/2, 3/4 AND FULL DEFLECTION.]

RUDDER INPUT	DEGRADATION

[PERFORM EASY ROLLING PUSH-OVERS AND PULL-UPS, NOTING ANY DEGRADATION. REPEAT AT INCREASING G LEVELS UNTIL DEGRADATION IS NOTED OR THE AIRPLANE LIMITS ARE REACHED.]

DESCRIBE THE MANEUVER (CONTROL DEFLECTIONS, G LEVELS ETC.):

DEGRADATION:

[EVALUATE THE ANTENNA STABILIZATION LIMITS DURING MISSION RELATABLE EVASIVE MANEUVERS AND WEAPON DELIVERY MANEUVERS.]

TYPE OF MANEUVERS____

DEGRADATION:

Card 27: Air-to-Ground Antenna Stabilization Limits Data Cards (Continued)

2.4.5. Minimum Range

2.4.5.1. Purpose

The purpose of this test is to determine the minimum range of the radar and its effects upon weapon delivery tactics.

2.4.5.2. General

The theoretical minimum radar range is discussed in the radar theory section. This is the absolute minimum range possible; however, the minimum range is usually something greater. The display is an important factor, as in the air-to-air minimum range. For a PPI display, the mapping video becomes very cluttered and often becomes a block of solid video close to the notch of the V from which a target cannot be resolved. Minimum range is critical in air-to-ground radars since highly accurate and frequent target position updates are required to place conventional ordnance on small tactical targets. The final target update is often the difference between a hit and a wide miss.

Note should be taken as to exactly what range is being measured while performing the minimum range test in order to properly interpret the results. The radar range is the line of sight from the radar to the target and can be envisioned as the hypotenuse of a triangle. One of the remaining sides of the triangle is then the altitude of the test airplane above the target. This implies that the minimum range measured can never be less than the altitude above the target. In addition, the lower antenna elevation angle fixes one of the adjacent angles in the line of sight, height, minimum range triangle so that the minimum range that can be measured becomes even greater than the test altitude above the target. For these reason, the test should be performed at as low an altitude as possible within the limitations of safety. 200 to 500 feet AGL are usually chosen for test purposes. Care must be taken to ensure that the effects of the lower elevation angle limits discussed earlier are not confused with the effects of the radar minimum range.

2.5.4.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.5.4.4. Data Required

Record the altitude and airspeed of the test airplane, target elevation, antenna elevation at the time detection is lost on the radar display and the displayed radar range. Record the time between loss of detection and overflight of the target. Make qualitative comments concerning the effects that the minimum range has upon the final target position updates.

2.4.5.5. Procedure

Descend to the test altitude. Choose a target of known altitude and designate it using the radar cursors. Use geostable cursors if available. If not, adjust the antenna elevation angle to optimize the target display. Proceed inbound to the target at a constant altitude. Continue to observe the radar display of the target as it converges to the bottom of the display. Lower the range scale to the minimum possible to display the target if the radar does not downscale automatically. Just as radar contact is lost, start the stop watch, record the displayed range to the target, altitude, airspeed and antenna pointing angle. Mark the elapsed time as the target is overflown. During mission relatable attacks, assess the effects that the minimum range has upon the ability of the radar to provide accurate, final target updates.

2.4.5.6. Data Analysis and Presentation

Check the antenna pointing angle at the time detection was lost to determine if it was at an angle less than the lower antenna elevation limit. If it was at the limit then assume that the minimum range is limited by the lower antenna elevation angle. If it was not at the limit, use the displayed radar range as the minimum radar range. Use the airspeed and time to overflight to confirm the radar derived range. Relate the minimum range to the likelihood that the target position will change in the case of a moving target, or that the last measured position will drift due to navigational errors for stationary targets, causing a reduction in weapon delivery accuracy.

2.5.4.7. Data Cards

A sample data card is provided as card 28.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND MINIMUM RANGE

[DESCEND TO ____ FEET AGL. SET ____ KIAS. DESIGNATE A KNOWN TARGET WITH THE GEOSTABLE CURSORS AND HEAD TOWARDS IT. WATCH FOR LOST DETECTION. RECORD THE DATA BELOW.]

TARGET_____________________

ALTITUDE OF TARGET (MSL)___________________

ALTITUDE AT LOSS (MSL)_______________________

AIRSPEED AT LOSS___________________

RADAR RANGE AT LOSS__________________

ANTENNA ELEVATION___________________

TIME FROM LOSS TO OVERFLIGHT__________________

[QUALITATIVE COMMENTS CONCERNING THE EFFECTS OF THE MINIMUM RANGE UPON LAST SECOND TARGET POSITION UPDATES.]

TYPE DELIVERY_____________________

EFFECTS:

Card 28: Air-to-Ground Minimum Range Data Card

2.4.6. Doppler Beam Sharpened Notch Width

2.4.6.1. Purpose

The purpose of this test is to determine the angular width of the DBS notch over the nose of the airplane and the effect that this notch has upon ingress and attack tactics.

2.4.6.2. General

The theory behind the DBS mode and the reason that the notch exists over the nose of the airplane is explained in the radar theory section. The notch is important since it limits the airplane from flying directly to the target while using the DBS mode. The effect that this has upon tactics depends on the width of the notch. For radars that fill the notch with real beam video, the break between the two is usually apparent and easily defined. The notch is still important is this case since the real beam filler does not have the resolution of the DBS picture and still requires maneuvering away from the direct inbound path to use the DBS mode on the target area. Typically, the notch is narrow enough that the DBS display can be centered on the nose of the airplane and the notch will be completely enclosed within the display with DBS video on either side, simplifying the measurement of the notch width.

2.4.6.3. Instrumentation

Data cards, a ruler and an optional voice recorder are required for this test.

2.4.6.4. Data Required

Record the angular width of the B scan format used for the test and mark on the edge of the data card both sides of the DBS display and both sides of the notch. During mission relatable ingresses and attacks, record qualitative comments on the effect that the notch has upon ingress tactics.

2.4.6.5. Procedure

With the airplane flying straight and level at a medium altitude, center the DBS display over the nose at approximately 20 to 30 nm and allow the display to build. Hold the data card up to the display, perpendicular to the DBS notch. Mark on the card the left and right side of the display and the left and right side of the notch. Perform mission relatable ingresses and simulated attacks using the DBS mode. Record qualitative comments concerning the effects upon tactics of not being able to fly directly to the target.

2.4.6.6. Data Analysis and Presentation

Use the ruler to determine the distance between the two tick marks on the data card that represent the edges of the DBS display and the distance between the two tick marks that represent the edges of the notch. Use equation 20 to find the DBS notch width.

$$NOTCH_{deg} = \frac{(NOTCH_{in})(B\ scan\ deg)}{(B\ scan\ in)} \tag{20}$$

$NOTCH_{deg}$=angular width of the DBS notch
$NOTCH_{in}$=linear width of the DBS notch on the B scan display
B scan deg=angular width of the B scan display section
B scan in=linear width of the B scan display

Relate the width of the notch to the requirement to zigzag to the target to keep it out of the notch and to the requirement to eventually put the target in the notch and rely upon the target stored position just before over-flying the target.

2.4.6.7. Data Cards

A sample data card is provided as card 29.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

DBS NOTCH WIDTH

[CLIMB TO ______ FEET MSL. SELECT DBS AND CENTER THE DBS MAP ON THE NOSE AT 20 TO 30 NM. HOLD THE DATA CARD UP TO THE DBS DISPLAY, PERPENDICULAR TO THE NOTCH, AND MARK THE EDGES OF THE DISPLAY AND OF THE NOTCH.]

DISPLAY ANGULAR WIDTH SELECTED ______________________________

[RECORD QUALITATIVE COMMENTS CONCERNING THE EFFECTS OF THE NOTCH UPON MISSION RELATABLE INGRESSES AND ATTACKS.]

EFFECTS:

Card 29: Doppler Beam Sharpened Notch Width Data Card

2.4.7. Range and Bearing Accuracy

2.4.7.1. Purpose

The purpose of this test is to determine how accurately the radar can determine the bearing and range to a radar target and the effect that this accuracy has upon ingress and attack tactics.

2.4.7.2. General

A precise range and azimuth accuracy test requires external space positioning data; however, an approximate check can be obtained by visually marking on top of a surveyed point and taking the radar derived range and bearing to another surveyed target. The pilot's mark on top technique is critical to this test and the test should be flown at as low an altitude as safety permits. An approximate rule of thumb for mark on top accuracy for an experienced evaluator is half of the altitude above the mark on top point. Range and bearing accuracy is important since it affects the utility of the vectors that the pilot gets from the radar as well as the target position input to the weapons delivery computer and to the seekers of stand-off weapons.

2.4.7.3. Instrumentation

Data Cards and an optional voice recorder are required for this test.

2.4.7.4. Data Required

Record the test airplane altitude, heading and radar derived bearing and range to a surveyed radar target as the test airplane marks on top of another surveyed point. Record qualitative comments concerning the utility of the radar derived bearing and range to the target during mission relatable ingresses and simulated target attacks.

2.4.7.5. Procedure

Before the test flight, select a visual target in the test area that has a surveyed latitude and longitude and a surveyed radar target at 15 to 20 nm away from the visual target. The radar target does not have to be in the test area. Descend to the test altitude. Fly a heading to the target that places the target within the radar search volume and keep the cursors as close to the target as possible. Perform a fly-over of the visual target. At fly-over, mark the bearing and range to the radar target, and then the test airplane altitude and heading. During mission relatable ingresses and simulated weapon deliveries, note the utility that the read out of target bearing and range provides as an aid for flying to the target and delivering weapons.

2.4.7.6. Data Analysis and Presentation

For radars that provide a relative bearing to the target, add a right target bearing to the test airplane heading to get the magnetic bearing to the target. Subtract a left bearing to the target to get the magnetic bearing to the target. Use the difference between the known latitudes and longitudes of the flyover and target points to calculate the north-south and east-west range differences. Use these ranges to solve for the hypotenuse of a right triangle. This is the approximate range between the fixes. The internal angles can then be solved for and added or subtracted from 0°, 90°, 180°, 270° or 360° to obtain the approximate true bearing between the points. Finally, variation is added to the true bearing to obtain magnetic bearing.

$$\Delta nm = (\Delta_{Lat})\left(\frac{1\ nm}{min}\right)$$
$$\Delta nm = (\Delta_{Long})\left(\frac{1\ nm}{min}\right)[\cos(LAT)] \qquad (21)$$
$$M_{bearing} = T_{bearing} + V$$

Δnm=the difference in nautical miles between the surveyed points along the north-south or east-west axis.
Δ_{Lat}=the difference between the latitude of the surveyed points in minutes.
Δ_{Long}=the difference between the longitude of the surveyed points in minutes.
Lat=the numerical average of the latitude of the two surveyed points in degrees.
$M_{bearing}$=actual magnetic bearing from the fly-over point to the radar target.
$T_{bearing}$=actual true bearing from the fly-over point to the radar target.
V=magnetic variation.

The difference between the actual and measured bearing and range are the bearing and range error. Relate the bearing and range error to the utility of the radar derived target position for navigating to the target and for input to standoff weapons.

2.4.7.7. Data Cards

A sample data card is presented as card 30.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND RANGE AND BEARING ACCURACY

[OVERFLY THE VISUAL POINT AT ___ FEET AGL AND ___ KIAS. DESIGNATE THE RADAR TARGET BEFORE FLY-OVER.]

VISUAL FLYOVER POINT____________________

RADAR TARGET______________________

BEARING/RANGE_________/__________

HEADING_______________

ALTITUDE_____________

[QUALITATIVELY EVALUATE THE UTILITY OF THE BEARING/RANGE ACCURACY FOR INGRESS NAVIGATION AND TARGET DESIGNATION FOR STAND-OFF WEAPONS.]

EFFECTS:

Card 30: Air-to-Ground Range And Bearing Accuracy Data Card

2.4.8. Range and Bearing Resolution

2.4.8.1. Purpose

The purpose of this test is to measure the range and bearing resolution of the radar and to assess the effects that the radar resolution has upon the utility of the radar for discriminating or "breaking out" targets closely spaced in range and bearing.

2.4.8.2. General

Theoretical range and azimuth resolution are discussed in the radar theory section. The radar display can have a pronounced affect upon resolution. The air-to-ground radar resolution is important because it allows the operator to break out individual targets in the target area, increasing the precision with which weapons can be delivered. As an example, high resolution may allow the operator to pick out individual airplanes on a ramp next to a hangar. This allows a direct attack of the airplanes rather than the hangar in the hope that the airplanes will be housed in the hangar.

Accurate range and bearing resolution tests are difficult to perform and require a significant amount of flight time to complete. For this reason, a qualitative evaluation will be performed first and if problems are noted with resolution, then the actual measurements will be obtained. The requirements for the range and bearing resolution are usually outlined in the detailed radar specification; however, if a specification is not available, an analysis of the intended mission and targets will allow the evaluator to choose a reasonable requirement. Once these are known, mission relatable targets should be chosen that are near these limits. Normally, a look at the layout of the evaluator's own airfield will provide a number of choices for the test. Isolated buildings with the appropriate separation make good targets. Isolation makes these buildings easy to find on radar since they are by themselves and are easily detectable, due to their size.

For range resolution, the targets should be aligned with the radar line of sight. The range to the targets is unimportant as long as they are detectable and are not so far away that the grazing angle causes the front target to mask the back target. Usually a range of 10 nm with a medium test altitude works well. For the azimuth resolution test, targets should be chosen that are separated by enough distance to allow the radar to break the targets out at around 10 nm given the minimum azimuth resolution requirement as described above. The desired target separation can be determined by solving a right triangle using the desired angular resolution as one internal angle and 10 nm as one of the adjacent sides. Again, the targets should be isolated to make them easy to find in the clutter and large enough to make them easily detectable beyond 10 nm.

Sometimes targets can be found that allow both tests to be flown in a single event. This requires that both sets of targets be roughly perpendicular in orientation. It is critical to ensure that the flight path is aligned perpendicular to the azimuth resolution targets. This is important since most radars are better at resolving targets in range than in azimuth. If the alignment is incorrect, the azimuth targets may break out in range and contaminate the azimuth resolution data point. The range resolution target alignment is conversely not as sensitive to the flight path. For radars with modes of differing resolution, the azimuth test can be performed in a single run by checking the best resolution mode first and then the rest as the range is closed.

As mentioned earlier, if the range and the azimuth targets are resolvable at the required range, then the range and azimuth resolution can be considered to be satisfactory and the test is complete. If not, then the radar will have to be flown against a radar resolution array to measure the actual range and azimuth resolution limits.

The radar resolution array is a set of surveyed radar reflectors arranged in a "T" shape. The top of the T provides the azimuth test and the base provides the range test. Corner reflectors are used for the targets and they generally have an optimum beam width of around 15°. The reflectors are optimized at some angle above the horizon. Since the array is aligned along an angle above the horizon, a constant flight path angle must be flown to the array. The best way to perform this maneuver is to choose a start range, and knowing the desired flight path angle, derive a start altitude. A reasonable descent speed should then be chosen and from that, a descent rate to arrive over the top of the target at a chosen minimum altitude. For example, using an angle of 10° above the horizon for the array alignment, a sea level array, and a 35 nm start range, the initial altitude would be 37,000 feet MSL. Using a 300 KIAS descent (disregard altitude/temperature/ position errors etc.) requires roughly a 7 minute trip to the target. A 200 feet AGL minimum altitude and a sea level target requires a 36,800 /7 feet/minute rate of descent to stay within the array alignment.

The resolution tests are difficult to fly because they require a steep descent at the correct flight path angle to stay within the vertical angular limits of the array while at the same time aligning the airplane along the centerline of the array and constantly monitoring the radar display for breakout. The horizontal angular width is particularly a problem for testing DBS modes since the DBS notch prevents the airplane from flying directly at the target. A zigzag pattern is required with quick turns to prevent missing the data point as the target passes through the nose.

For the range test, the maximum number of targets broken out of the base of the T at any time during the run is recorded. Theoretically, range will not affect the number; however, arrays sometimes are made of more than one size target and the smaller targets will not break out until the test airplane is close to the array. The targets are arranged with differing separations, usually the widest spaced target at the base and the closer spacing towards the top of the array.

2.4.8.3. Instrumentation

Data cards, a radar resolution array and an optional voice recorder are required for this test.

2.4.8.4. Data Required

For the targets chosen at the home field, record whether the targets aligned along the flight path can be broken out and for the targets aligned perpendicular to the flight path, record the range at which they can be broken out. While using the radar resolution array, record the total number of targets found during the run aligned along the base of the T and the range and total number of targets broken out as each new target becomes resolvable at the top of the T. During mission relatable ingresses and attacks, record the effects that the radar resolution has upon the utility of the radar for finding individual targets that are closely spaced in range and/or azimuth.

2.4.8.5. Procedure

Before the flight, determine the requirements of the radar for range and bearing resolution. Obtain a diagram of the home airfield or some other field in the vicinity of the test area. Find two targets, such as buildings, that are spaced near the range resolution requirement. Using the required angular resolution limit, find two other targets that are spaced so that they should break out at 10 nm of range. If possible, choose the two sets of targets so that they can be flown simultaneously, that is, aligned perpendicularly. Climb to a medium altitude and fly inbound along a ground track aligned with the range targets. Continue inbound until the targets break out or until overflight. Record if breakout occurs. Starting at 15 nm, fly inbound along a heading perpendicular to the orientation of the azimuth targets. Continue inbound to 10 nm, noting if breakout occurs. If two sets of targets were found that were roughly perpendicular so that the tests could be flown in one run, care should be taken to be as close to perpendicular to the alignment of the azimuth resolution targets as possible. If the range targets break out at any time and the azimuth resolution targets break out by 10 nm, then flying against the resolution array is not required.

If the resolution array is required, use the technique outlined earlier to determine the initial altitude, airspeed and rate of descent to the array. For a non-DBS mode without a notch, start at the initial point and head directly to the array aligned along the base of the T. Care should be taken to remain within the beam width of the array corner reflectors. Reduce the rate of descent early enough to allow a comfortable arrival at the minimum altitude at overflight of the array. Record the maximum number of range targets broken out, and the range and number of targets broken out each time a new target becomes resolvable. For a DBS mode, a direct route along the center of the beam width to the array will not be possible since the target cannot be in the DBS notch. A zigzag course is required, turning when the magnetic bearing to the target approaches the centerline plus or minus the beam width. Quick turns are required so that it will be unlikely that a breakout will occur during the time of the turn. Record the same data as for the real beam test. During mission relatable ingresses and attacks, note the effects that the range and bearing resolution has upon the ability of the radar to discriminate targets spaced closely in range and bearing.

2.4.8.6. Data Analysis and Presentation

If the radar was able to break out the mission relatable range target at any range and the azimuth targets by 10 nm and no problems were noted during the mission relatable ingresses and attacks, then the range and azimuth resolution is satisfactory. If the radar was not able to break out the targets, relate the poor resolution to the ability of the radar to break out mission relatable targets and the requirement to visually designate individual targets. Count off the resolution array range targets from widest spacing to closest until one minus the total number seen are accounted for. The range resolution will be at least the spacing of the last target accounted for. For example, using data card 31, if 4 targets are seen, the resolution will be at least 100 feet. For the azimuth test, using the range to the targets and the range between them, a right triangle can be solved for the angular resolution at each target breakout. Again, using the array depicted on data card 31, if 3 targets are broken out at 10 nm, the angular resolution is:

$$\textit{Angular Resolution} = \frac{(300\ \textit{feet})}{(10\ \textit{nm})\left(6076\frac{\textit{feet}}{\textit{nm}}\right)} \qquad (22)$$

Use the data to support the qualitative evaluation. Relate any additional problems noted during the ingresses and attacks.

2.4.8.7. Data Cards

Sample data cards are presented as card 31.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND RANGE AND BEARING RESOLUTION

[CLIMB TO ______ FEET MSL, SET _______ KIAS. FIND THE RANGE AND AZIMUTH TARGETS AND DESIGNATE THEM WITH THE CURSORS. SET UP TO FLY ___° MAGNETIC HEADING INBOUND TO THE TARGET STARTING AT 15 NM. RECORD IF THE RANGE TARGETS BREAK OUT AND IF THE AZIMUTH TARGETS BREAK OUT BY 10 NM. REPEAT FOR EACH MODE.]

MODE	RANGE TARGETS BREAK OUT (YES/NO)	AZIMUTH TARGETS BREAK OUT (YES/NO)

RANGE AND AZIMUTH RESOLUTION QUALITATIVE TARGETS:

{ADD A TARGET AREA DIAGRAM HERE TO AID IN TARGET AREA ORIENTATION.}

Card 31: Air-to-Ground Range and Bearing Resolution Data Cards

AIR-TO-GROUND RANGE AND BEARING RESOLUTION

[CLIMB TO ______FEET MSL AND SET ___ KIAS. PROCEED TO A POINT __ NM AWAY FROM THE ARRAY ORIENTED ALONG THE ___ BEARING TO THE TARGET. ACQUIRE THE ARRAY ON RADAR AND DESIGNATE WITH THE CURSORS. STAY IN THE BEAM WIDTH OF THE ARRAY. USE A _____ FEET/MINUTE RATE OF DESCENT. REPEAT FOR EACH RADAR MODE.]

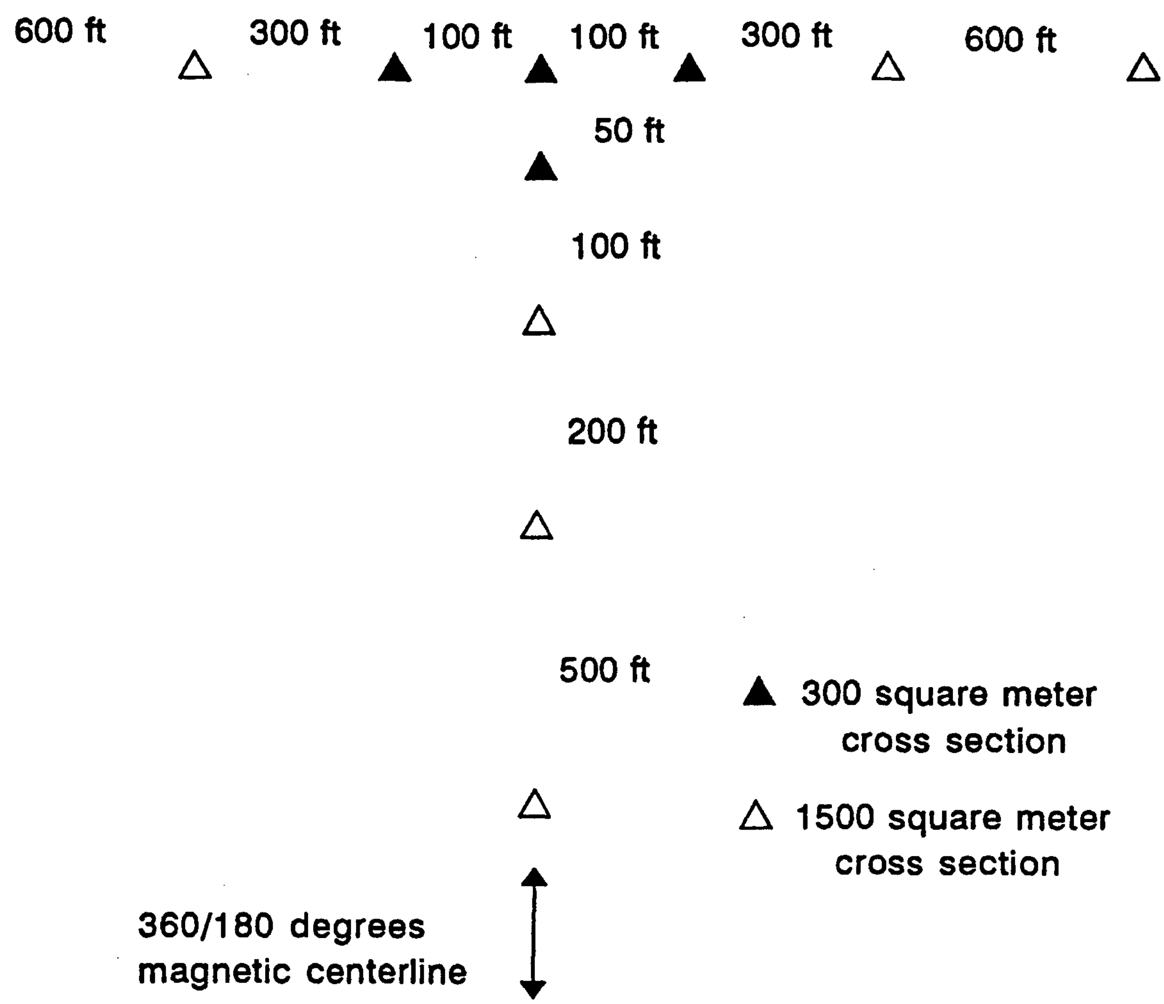
MODE	MAXIMUM NUMBER RANGE TARGETS	AZIMUTH TARGETS NUMBER/RANGE

[RECORD QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE RADAR TO BREAK OUT TARGETS CLOSE IN AZIMUTH AND RANGE.]

EFFECTS:

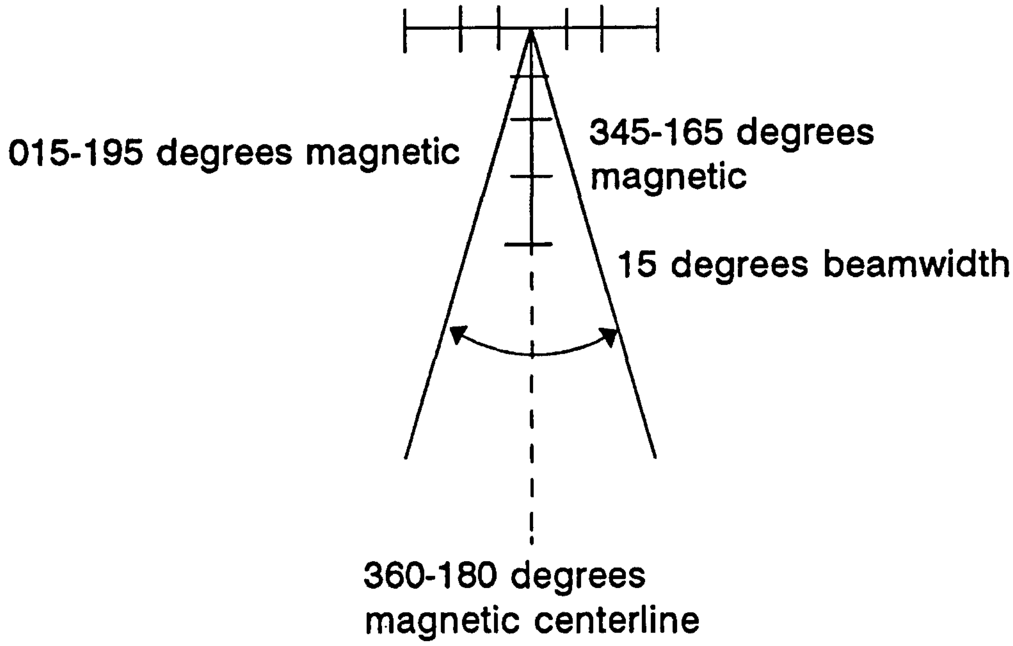
Card 31: Air-to-Ground Range and Bearing Resolution Data Cards (Continued)

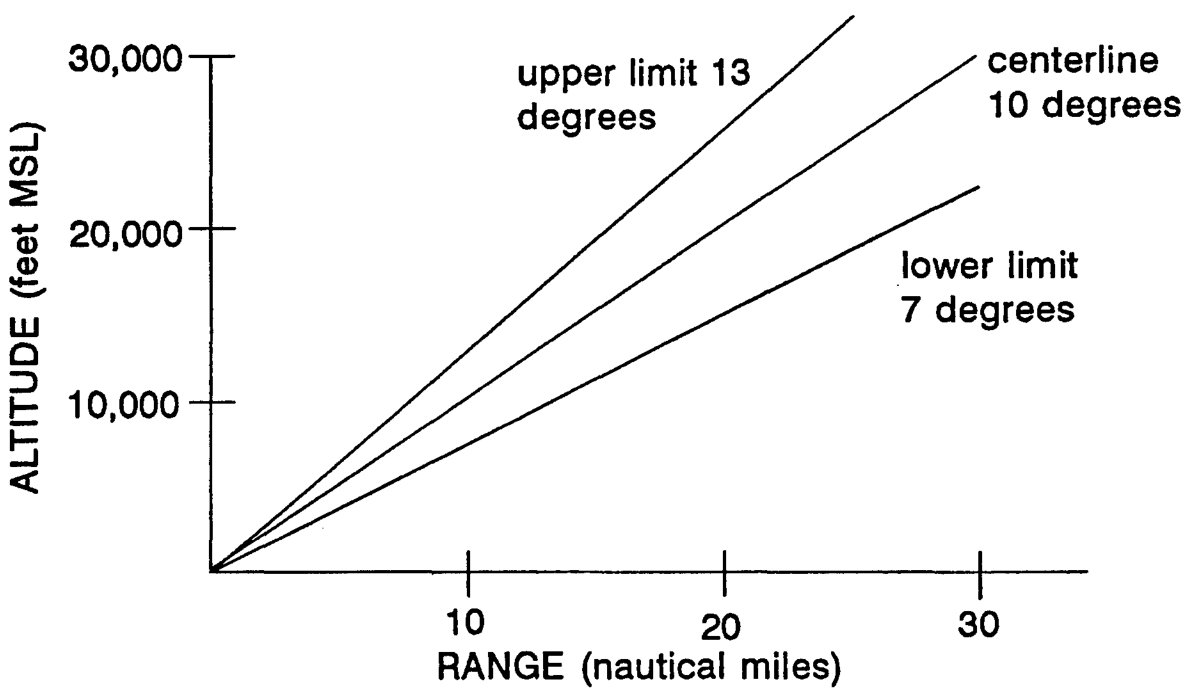
RESOLUTION ARRAY DIAGRAM



Card 31: Air-to-Ground Range and Bearing Resolution Data Cards (Continued)

RADAR RESOLUTION ARRAY DIAGRAM





Card 31: Air-to-Ground Range and Bearing Resolution Data Cards (Continued)

2.4.9. Maximum Detection Range

2.4.9.1. Purpose

The purpose of this test is to determine the maximum range at which the radar detects any radar target, the maximum range that can be used for rough navigational orientation, the maximum range that the radar can effectively detect and present a mission relatable target and the effects that these ranges have upon ingress and attack tactics.

2.4.9.2. General

As with air-to-air radars, the air-to-ground maximum range is an important and high interest data point. The air-to-ground maximum range is much more ambiguous than the air-to-air maximum range, and so the exact definition of the maximum range value desired must be provided. For this test, three values will be obtained; first, the maximum range at which any radar returns are received; second, the maximum range at which the radar display is usable for a rough navigational aid and as an aid in positional SA; third, the maximum range at which a mission relatable target can be detected and identified.

The test airplane altitude above the terrain is important for air-to-ground maximum range tests since the maximum displayed range will typically not be beyond the radar horizon. Knowing the test airplane height above the terrain, the radar horizon can be approximately calculated using the following relationship [Ref. 27:p.4-1.3]:

$$R_{horizon}=1.23\sqrt{H} \tag{23}$$

$R_{horizon}$=radar horizon in nm

H=altitude above the terrain in feet

A test altitude should be chosen that places the radar horizon beyond the maximum display range of the radar to ensure that the maximum ranges displayed are a result of the radar performance and not the geometry of the test. The maximum displayed range data point requires recording the range at which any radar video is displayed. The maximum range for navigation orientation is the maximum range at which the display is coherent enough and of sufficient quality to discern large geographic features such as specific mountain ranges, large peaks, coastlines and bays. The maximum range against mission relatable targets is the range at which small to medium cultural features (bridges, railways, buildings etc.) can be resolved from the background clutter. It is important to describe the target used for the data point in addition to noting the ranges. It should also be noted that the maximum detection range can sometimes vary greatly from one data point to the next. Usually, a statistically significant set of data points are required. Sample size selection depends mainly upon the variance of the measurements from one test to the next and is discussed in detail in references 43 and 72.

2.4.9.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

2.4.9.4. Data Required

Record the target (if known) and the range for the maximum range displayed video, the maximum range at which targets are displayed that are useful for rough navigation and orientation, and the maximum range at which mission relatable targets are broken out of the clutter. During mission relatable ingresses, note the effects that the maximum radar ranges have upon tactics.

2.4.9.5. Procedure

Before the test flight, analyze a tactical pilotage chart to determine the targets available within the display volume of the radar while in the test area. Try to find a series of targets out to the edge of the display range that satisfy the requirements for rough navigation and for tactically significant targets. A coastline with the associated bays and rivers or a mountain with a series of peaks is useful to find the maximum range for rough navigation. A series of bridges along a river or a series of isolated buildings along a highway can be used as small to medium tactical targets. Choose a test altitude that assures that the maximum display range is unobstructed by the radar horizon using equation 23.

Start the test at one end of the working area, heading towards the other end. Set a 30° to 60° scan angle limit and a range scale that just includes the maximum range at which radar returns are displayed. Mark the maximum range at which radar video is displayed and the target if known. Next, record the maximum range at which features are just usable for rough navigation. Record the feature that is identified using the radar. Finally, record the range at which tactically significant targets become recognizable along with the identity of the target. Repeat for each radar mode. During mission relatable ingresses, record the effects that the maximum radar ranges have upon ingress and attack tactics.

2.4.9.6. Data Analysis and Presentation

Relate the maximum range at which any radar returns are detected to the absolute maximum range at which a coast line or a large mountain range can be detected. Relate the maximum range at which the radar can be used for rough navigation to the requirement for long range orientation and SA. An example is finding a river outlet for a coast-in point. Relate the maximum range that mission relatable targets become discernable to the requirement to find targets of opportunity far enough away to perform a safe ingress and to optimize the attack on the target. During mission relatable ingresses, use the radar display and a tactical pilotage chart to orient within the target area and attempt to acquire the target at the longest possible range. Assess the utility of the maximum ranges of the radar during these runs.

2.4.9.7. Data Cards

A sample data card is presented as card 32.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND MAXIMUM DETECTION RANGE

[CLIMB TO _____ FEET MSL AND SET ___ KIAS. SELECT A SEARCH MODE WITH A __° SCAN ANGLE LIMIT AND A ___ NM RANGE SCALE. START IN THE ____ CORNER OF THE WORKING AREA AND HEAD ___° . REPEAT FOR EACH MODE.]

MODE	MAXIMUM RANGE VIDEO DISPLAYED (TARGET/RANGE)	MAXIMUM RANGE ROUGH NAVIGATION (TARGET/RANGE)	MAXIMUM RANGE MISSION TARGETS (TARGET/RANGE)

[ASSESS THE EFFECTS OF THE MAXIMUM RANGES WHILE NAVIGATING AND DETECTING THE TARGET DURING MISSION RELATABLE INGRESSES.]

EFFECTS:

Card 32: Air-to-Ground Maximum Detection Range Data Card

2.4.10. Mapping Quality and Consistency

2.4.10.1. Purpose

The purpose of this test is to evaluate the mapping quality and consistency and to assess the effects these parameters have upon the utility of the radar for orientation and navigation.

2.4.10.2. General

Ideally, the radar mapping display would look like a photograph of the search volume. This ideal display could easily be correlated to the geographic features on a tactical chart and thus used for navigation updates. The display would also be perfectly consistent to the edge of the scope with no variations in the quality of the display and no blank areas. Cultural features and targets would appear just as they do visually and would be easily discernable. The purpose of this test is to find how closely the real radar mapping display comes to this goal.

2.4.10.3. Instrumentation

Data Cards and an optional voice recorder are required for this test.

2.4.10.4. Data Required

Record qualitative comments concerning the consistency of the radar display from the minimum range to the edge of the detection area as well as the fidelity of the display in presenting a map-like picture of the search volume. During mission relatable ingresses, record the utility of the display for orientation and navigation.

2.4.10.5. Procedure

Climb to the altitude used for the maximum range test and select a range scale that includes the maximum range radar returns. Select the widest antenna scan angle limits and optimize the antenna pointing angle for maximum range detection and then for a display at 1/2 of the maximum range returns. Make qualitative comments concerning the mapping quality and consistency. Repeat using all the radar mapping modes. Descend to a moderately low altitude and repeat the series. During mission relatable ingresses, assess the utility of the mapping quality and consistency for orientation and navigation to the target.

2.4.10.6. Data Analysis and Presentation

Relate the mapping quality and consistency to the utility of the radar for long range navigation, geographic orientation and for finding targets at long range. Pay particular attention to the change in mapping consistency as the antenna elevation angle is changed. If poor consistency is noted close to the test airplane while searching at long ranges, relate this to the requirement to obtain navigation updates while still searching at maximum ranges for targets.

2.4.10.7. Data Cards

A sample data card is presented as card 33.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

MAPPING QUALITY AND CONSISTENCY

[CLIMB TO _____ FEET MSL AND SET ___ KIAS. SELECT A __° SCAN ANGLE LIMIT, OPTIMIZE THE ANTENNA TILT FOR LONG RANGE DETECTION AND, SET THE RANGE SCALE TO JUST INCLUDE ALL OF THE DISPLAYED VIDEO. MAKE QUALITATIVE COMMENTS. REPEAT FOR ALL MAPPING MODES. REPEAT WITH THE ANTENNA TILTED TO OPTIMIZE DETECTION AT 1/2 THE MAXIMUM DETECTION RANGE. REPEAT AT _____ FEET AGL.]

	MODE	SCALE	FAR/MID	COMMENTS
HIGH				
LOW				

[RECORD QUALITATIVE COMMENTS CONCERNING THE EFFECTS OF THE MAPPING QUALITY AND CONSISTENCY DURING MISSION RELATABLE INGRESSES.]

EFFECTS:

Card 33: Mapping Quality and Consistency Data Card

2.4.11. Mission Utility and Integration

2.4.11.1. Purpose

The purpose of this test is to qualitatively assess the overall utility of the radar for the assigned mission and the integration and compatibility of the radar performance parameters, controls and displays within the airplane.

2.4.11.2. General

The mission utility and integration test is the most important test of the series. During this test, mission relatable ingresses and attacks are performed to qualitatively assess the radar. The quantitative assessments of the previous tests are used to support and justify the qualitative determinations made during the ingresses and attacks. Utility refers to the overall usefulness of the radar as it is implemented, as an aid to the mission. The radar parameters must match the expected operational needs. Integration refers to the way the radar has been blended into the entire airborne system. From the evaluator's standpoint, this characteristic is intimately tied into the area of human factors. The qualitative assessments in mission relatable scenarios specifically called for in the previous tests will also be performed during these ingresses and attacks.

Care should be taken to ensure that the evaluator does not get too involved in recording qualitative comments to the detriment of watching the progress of the intercept and evaluating the radar. A conscious effort should be made not to get too involved in looking for specifics on at least the first run to ensure that an overall qualitative assessment can be made. A voice recorder can be used to make comments without distracting the evaluator from the display or the outbound run can be used to record results. Multiple runs should be performed using different radar modes and mode combinations in as many different types of attacks as possible. The most likely scenarios should be performed first and others performed as flight time allows.

2.4.11.3. Instrumentation

Data cards are required for this test. A voice recorder is highly recommended.

2.4.11.4. Data Required

Record qualitative comments concerning the utility and integration of the radar. Record the effects of the parameters determined in previous tests during the ingresses and attacks as called for at the end of each test procedure.

2.4.11.5. Procedure

Select a mission relatable target in the test area that allows for a 35 to 40 nm ingress to the target location. Descend to a low ingress altitude and set an airspeed which would normally be selected for an attack of a defended target. Head inbound to the target and select a radar mapping mode with at least a 40 nm scale and a wide scan pattern useful for radar navigation. Perform radar navigation inbound to the target (for instance following a river or ridge line that leads to the target) and search for the target on the display. Continue to update the antenna elevation angle, display range and antenna pointing angle to optimize the display for navigation and target search. When the target breaks out, select the DBS modes and continue to update the target position. Execute the type weapon delivery most likely for the test airplane and the type of target selected. Turn outbound, selecting a mapping mode and navigate outbound from the target area to the start point. Repeat the ingress and attack using different delivery modes and if available, different target types.

2.4.11.6. Data Analysis and Presentation

Relate the qualitative deficiencies noted to their effects upon the performance of the ingresses and attacks. Note any limitations on tactics imposed by the radar parameters, utility or integration. For instance, the radar may not be able to detect the target early enough to set up and fire stand off weapons (that don't use external targeting) at their maximum range. The radar should not be driving tactics. Use the applicable results from the previous tests to support the qualitative results.

2.4.11.7. Data Cards

A sample data card is presented as card 34.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

AIR-TO-GROUND MISSION UTILITY AND INTEGRATION

[DESCEND TO ___ FEET AGL AND SET MACH=___. SELECT THE MAP MODE, ___ NM RANGE SCALE AND THE __° SCAN ANGLE LIMIT. START AT ________________ AND FLY INBOUND TO THE _________________ TARGET AT AN INITIAL HEADING OF ___. RADAR NAVIGATE TOWARD THE TARGET AREA AND WHEN IN CONTACT WITH THE TARGET SELECT DBS. PERFORM A SIMULATED ____________DELIVERY. TURN OUTBOUND AND NAVIGATE BACK TO THE START POINT. REPEAT WITH DIFFERENT DELIVERIES AND TARGETS.]

NOTES:

Card 34: Air-to-Ground Mission Utility and Integration Data Card

2.4.12. Introduction to Advanced Air-to-Ground Radar Test Techniques

As mentioned in Chapter 1, only the most rudimentary form of the air-to-ground radar test techniques are presented in this book. Chapter 1 details the reasons for this format; however, in many applications, more rigor, accuracy and documentation of results are required. Table II outlines additional instrumentation and assets which are typically applied in these more advanced tests. The purpose of this table is merely to emphasize the existence of these advanced techniques. Further, this list is not exhaustive. Many innovative uses of assets and instrumentation exist. It is hoped that the examples provided leave the reader with a taste of how the test can be made more rigorous through the judicious use of instrumentation. In application; the user must refer to the more advanced documents referenced in Chapter 1 or solicit help from more experienced testers.

Table II: Additional Assets or Instrumentation for use in Advanced Air-to-Ground Radar Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Scan Rate.	Digital recording of radar data.	In some systems the sweep position can be digitally recorded as output of a scan converter. In this case the instantaneous as well as the average scan rate can be calculated as required.
	Time stamped video recording of display.	Even in the absence of digital data, the instantaneous and average scan rates can be derived using appropriately time stamped video.
Scan Angle Limits.	Digital Recording of time stamped aircraft heading and position, time stamped video recording of display and a geographically surveyed ground target.	The test can be made more accurate by recording the precise time, the precise test aircraft location and heading (these parameters are either derived and recorded on-board or using a space positioning range as appropriate), and using a target with a precisely surveyed location. The radar display is video recorded and time stamped and as the target disappears, the exact angle off boresight can be derived based upon geometric calculations.
Elevation Angle Limits.	Similar to scan angle limits except vertical angles are recorded vice headings.	Similar to scan angle limits except the vertical angles to the target are calculated vice the horizontal angles.
Antenna Stabilization Limits.	Digital recording of test aircraft time stamped roll, pitch and yaw rates and time stamped video recording of the display.	The direct measurement of the roll, pitch and yaw rates are correlated to degradation on the time stamped display.

 Table II: Additional Assets or Instrumentation for use in Advanced Air-to-Ground Radar Tests (Continued)

Test	Additional Asset or Instrumentation	Purpose/Benefit
Minimum Range.	Time stamped video recording of display, digital recording of time stamped digital radar data, time stamped recording of test aircraft location and surveyed radar target.	The loss of detection on the display is time correlated with the recorded aircraft and known target positions to derive the minimum detection range. Range space positioning data or onboard instrumentation may be used to derive the test aircraft position. Recorded radar data can be correlated with the display output to isolate any problems as either radar or display related.
Doppler Beam Sharpened Notch Width.	Video recording of radar display.	The video recording can be used to make more accurate and liesurely ground measurements.
Range and Bearing Accuracy.	Digital recording of time stamped test aircraft position and time stamped radar display video or digital radar data with radar derived bearing and range to a surveyed target.	Test aircraft location from either onboard instrumentation or range space positioning data are used to calculate the actual range and bearing to a surveyed target at the time a range and bearing is derived using the radar. The video recorded range and bearing or the range and bearing from the digitally recorded cursor position are compared directly.
Range and Bearing Resolution.	Digital recording of time stamped test aircraft location. Time stamped video recording of the radar display. Surveyed resolution array.	The resolutions can be directly determined by geometrically comparing the positions of the surveyed targets and the test airplane at the time breakout occurs. Range space positioning data or onboard instrumentation may be used to derive the test aircraft position.
Maximum Detection Range.	Video recording of time stamped radar display. Time stamped test aircraft location. Propagation prediction assets. Real time measurement of casual interference. Surveyed target locations.	The test aircraft and surveyed target locations are geometrically reduced to provide actual, time stamped locations of the targets in radar space. This information is used to validate hits and misses at corresponding bearings and ranges on the targets as recorded on the radar display. Often, the real time propagation performance is predicted on instrumented ranges for the frequency of the test radar and casual interference is recorded on the aircraft using special instrumentation. Sometimes this information is already designed into the test radar and needs only to be recorded.
Mapping Quality and Consistency.	Video recording of the radar display.	Video recording allows repeated vewing while on the ground.

Table II: Additional Assets or Instrumentation for use in Advanced Air-to-Ground Radar Tests (Continued)

Test	Additional Asset or Instrumentation	Purpose/Benefit
Mission Utility and Integration.	Digital recording of precise, time stamped test aircraft position, rates and accelerations; surveyed targets; digital recording of time stamped radar data; time stamped video recording of radar and head up display.	This test requires the largest amount of data to completely document the results. It is during this test that most of the unexpected problems are found. In anticipation of having to document these deficiencies, maximum instrumentation and range support are sometimes brought to bear in case unforseen data are required in post-flight analysis.

3.0. AIRBORNE NAVIGATION SYSTEMS TESTING

3.1. INTRODUCTION TO NAVIGATION THEORY

3.1.1. General

The purpose of any airborne navigation system is to determine aircraft position, velocity and orientation relative to a specified reference point, using some coordinate system optimized for use on the host platform. For most airborne navigation systems, the preferred reference point is fixed at the center of the earth. The earth center reference point is moving around the sun which is in turn moving fairly linearly through space. By fixing the reference point to the center of the earth, these motions can be ignored, leaving only motion of the point on the earth's surface at which the aircraft is located relative to the earth's center (the only significant factor is earth rotation for the mission durations of airborne systems) and movement of the aircraft across the earth's surface.

The coordinate system of most use in airborne applications is a spherical system using latitude, longitude and altitude. Due to system limitations, many electronic navigation systems actually operate referenced to a point on the earth (for instance the position of an electronic navigation aid ground station) and using a cylindrical coordinate system of bearing, range and altitude centered at the point. [Ref. 38:p. 1.1]. In some cases, such as in long range, great circle navigation, the pilot is best able to orient in spherical coordinates (latitude, longitude and altitude). In other cases, for instance during an ingress and attack of a surface target, the pilot is best able to orient in a cylindrical format (bearing, range and altitude) referenced to the position of the target. Often a conversion can be made, which may be transparent to the operator, between the two coordinate systems.

Navigation systems can be divided into the broad categories of position fixing and Dead Reckoning (DR) navigation systems. In position fixing, the system determines the location of the host aircraft at a discrete point in time. Position fixing systems tend to be very accurate, compared to DR systems, at the time the location is measured but will drift in accuracy in the short term as the host aircraft moves between fixes. Long term accuracy is good since the position is updated at intervals. DR systems continuously estimate position as the host aircraft moves within the coordinate system by integrating platform acceleration and/or velocity to obtain the change in coordinate values and then adding them to the initial position coordinate values. DR systems tend to have good short term accuracy following the initial fix; however, the long term accuracy degrades as errors accumulate since the reference position is not updated. [Ref. 38:p. 1.3]. The strengths of both systems can be exploited by combining a position fixing and DR system into a single integrated navigation system. A DR system is used to provide optimum short term accuracy while the position fixing system provides periodic position updates for the best long term accuracy. [Ref. 38:p. 1.2].

A variety of DR systems are used in modern aircraft. The most common are Inertial Navigation Systems (INSs) and Doppler Navigation Systems. A larger number of position fixing systems are available, including Tactical Air Navigation (TACAN), VHF Omnidirectional Ranging with Distance Measuring Equipment (VOR/DME), Long Range Navigation (LORAN), OMEGA and the satellite based Global Positioning System (GPS). These systems are tested in essentially the same manner, using the same basic techniques. To illustrate the DR, position fixing and fully integrated position fixing/DR test techniques, two sample systems will be used. The first system is a semi-analytic, north seeking INS, augmented with a visual, radar, OMEGA and TACAN update mode. The combining and coupling of the position fixing and DR systems is minimal, and so the test techniques are developed as essentially stand-alone DR and position fixing routines. The second system is a fully integrated GPS/INS. It will be seen that the test procedure is an adaptation of the tests developed for the stand-alone DR and position fixing systems.

In order to limit confusion between the discussion of the two sample systems, treatment of the second system will be delayed until after the presentation of the OMEGA tests. This will be a minor departure from the format of the radar and electro-optical sections, where all the system theory is provided at the beginning of the chapter, but it will enhance readability. A single exception is the Preflight and Built in Tests procedures.

3.1.2. Inertial Navigation Systems

3.1.2.1. Components

INSs are composed of two basic components, gyroscopes and linear accelerometers. Linear accelerometers are used to measure acceleration along the axis in which the device is oriented. [Ref. 38:p. 2.10]. If the linear accelerometer is accelerated in a direction not aligned along the axis of orientation, it will measure the vector component of the acceleration along the axis of orientation. In airborne INS systems, at least three orthogonally aligned accelerometers are used and the measured acceleration of the three are vectorially added to gain the actual acceleration vector value. There are two types of gyroscopes. Position gyroscopes measure rotational displacement of the gyroscope case (which is usually attached to the airborne host platform) around the input axis as measured from some initial position. Rate gyroscopes measure the rotational rate of the gyroscope case around the input axis. Both types of gyroscopes rely on "the fact that a rotating (spinning) element tends to maintain its spin axis in a direction fixed with respect to inertial space". [Ref. 38:p.2.12]. Inertial space is referenced to a fictional point that is not moving relative to all matter in the universe.

3.1.2.2. Analytic/Semi-Analytic and North Pointing/Wander Azimuth Systems

In most INSs the gyroscopes (whether displacement or rate gyroscopes) are used for one of two purposes. In the analytic system, the frame of reference is stabilized in inertial space. [Ref. 38:p.2.6]. In this case, the three-dimensional coordinate system remains fixed in space and as the earth rotates, the earth revolves around the sun, and the host platform moves across the earth, the three reference planes appear to rotate when compared to local vertical and the true north direction. The gyroscopes measure the host airplane orientation in inertial space, the accelerometers measure all acceleration relative to inertial space and the results are manipulated mathematically to determine accelerations actually due to movements across the earth's surface and due to changes in altitude above the earth. This process is extremely complicated and computer intensive and so most INSs use a semi-analytic system in which the gyroscopes are used to orient the accelerometer array, and thus the local horizontal reference plane, perpendicular to local vertical for the host platform's position on the earth. This leaves one reference plane perpendicular to local vertical and the altitude axis coincident to local vertical. The plane perpendicular to the local vertical is known as the platform. Continuous correction of the platform orientation as the earth rotates and the host aircraft moves over the surface of the earth is required but this method allows for mathematical corrections for the gravitational vector to be added in a single axis and for measurements of movement across the face of the globe to be made directly in two dimensions. [Ref. 38:p. 2.17].

In the case of a north pointing, semi-analytic system, not only is the platform maintained relative to local vertical but one of the two axes defining the plane is always oriented to true north, allowing for direct measurement of displacement in latitude, longitude and altitude. Wander azimuth systems do not physically maintain the alignment of the platform with the true north reference but use the output of the gyroscopes to maintain track of where true north is located. The output of the accelerometers located in the reference plane are then vectorially resolved into north-south (latitude) and east-west (longitude) components. This process uses more computer computations but does not require continuous alignment of the platform accelerometers with true north. A semi-analytic, wander azimuth type INS will be used as the sample system for development of the test techniques to be presented later.

3.1.2.3. Vertical Tracker

The vertical tracker portion of the semi-analytic INS is designed to maintain the INS platform orientation orthogonal to the local vertical. The clearest way to envision this is to imagine a cable stretched from the center of the earth to the host aircraft INS. By aligning the INS platform relative to the cable as the host aircraft moves across the face of the earth, the correct orientation can be maintained. This is equivalent to attaching the host aircraft to the end of a pendulum of length equal to the radius of the earth. This is known as a

Schuler pendulum, which has a period of 84.4 minutes. [Ref. 38:pp. 2.19-2.21]. An equivalent Schuler pendulum can be mathematically modeled within the INS computer and combined with a mathematical model of the earth's rotation rate and host aircraft latitude and altitude to calculate the direction of the local gravity vector. The platform is then physically aligned perpendicular to this calculated gravity vector.

Two additional platform corrections are required for an INS moving across the earth's surface. As the INS moves in an east-west direction, the effective rotation rate of the local vertical due to the earth's rotation must be decreased for a westerly velocity and increased for an easterly velocity. In addition, as the INS is moved in a north-south direction, the distance to the earth's center of rotation changes. The Coriolis force then causes an easterly acceleration for north velocities and a westerly acceleration for a southern velocity. These corrections must be calculated within the INS computer and the corrections accounted for, or the local gravity vector, and thus the platform alignment and the north-south and east-west accelerations, will be incorrect. [Ref. 38:pp. 2.21-2.22].

The Schuler pendulum has an interesting effect upon the output of the INS as errors are induced on the vertical tracker. As the orientation of the platform is tilted from the exact local vertical, the gravity vector will be sensed in the horizontal channel. The acceleration error due to gravity is cyclic and has a period of 84.4 minutes and is known as a Schuler cycle. The Schuler cycle is characteristically undamped and so many INSs will use an independent input (often a velocity input from a source such as a doppler navigation system) to damp out the Schuler oscillations and to correct the vertical axis error. [Ref. 38:pp.2.24-2.25].

Much has been said about the local gravity vector without actually defining its value. The local acceleration due to gravity can vary in magnitude due to both host aircraft altitude and local anomalies and in direction due to the fact that the earth is not exactly round but a non-homogeneous, oblate spheroid. The actual value can be modeled by a complicated expression including as much as thirty-two terms; however, most INSs use a much simpler model and rely upon periodic updates to correct the resultant inaccuracies. Local gravitational anomalies can cause as much as a one nm/hour error in INS derived velocities. [Ref. 38:pp. 2.9,2.26].

3.1.2.4. The Vertical Channel

The vertical channel of the INS is unstable. This results from the fact that the local gravity vector decreases in magnitude as the altitude above the center of the earth increases. When the second derivative of the vertical acceleration is taken to determine the vertical axis positional change (altitude change) a negative value of the zero derivative gravitational change correction for altitude must be added. The resulting second order relationship is unstable. Methods exist for providing the feedback necessary to damp this phenomenon and to provide better altitude and vertical velocity determination; however, sufficient altitude accuracy is achievable by much cheaper and simpler methods and so most tactical aircraft INSs do not use the vertical INS channel. [Ref. 38:p. 2.27-2.28]. The sample system to be used for the development of the test techniques to follow will not use a vertical channel.

3.1.2.5. The Horizontal Channel

Understanding the vertical seeker and the vertical channel, the horizontal channel can now be described. Starting with a level platform, the INS accelerometers measure acceleration perpendicular to the local vertical. The INS calculates and adds corrections for the coriolis effects, centrifugal acceleration (due to earth rotation) and local acceleration due to gravity including aberrations/altitude corrections. The sum is then integrated to get rates. The rates are then sent back as input to the vertical seeker feedback loop and then integrated again to get the change in position. The change is added to the original position to get the new position. [Ref. 38:p. 2.26a].

3.1.2.6. Initialization and Alignment of the INS

Since the INS is a DR type navigation system, it must have an initial position and orientation from which to navigate. For the semi-analytic, north seeking INS, the level platform and initial true north reference must be established before navigating from the initial latitude-longitude position. The process is performed in two stages, platform leveling and gyrocompassing, which may be performed concurrently for at least a part of the process. Platform leveling is the process by which the platform is physically oriented perpendicular to the local vertical. Gyrocompassing is the process by which the semi-analytic platform reference is aligned with true north. [Ref. 38:p. 2.36-2.37].

After the present latitude and longitude of the INS is entered into the INS computer, the process begins with coarse leveling, where the platform gimbals are aligned with preset angles with respect to the host aircraft. Next, the north azimuth of the platform axis is rotated to an alignment with north as provided by the aircraft magnetic compass. At this point, the coarse leveling and alignment process is complete and a feedback process is begun to refine the leveling and alignment process.

In the fine leveling process the gravity vector is used as the feedback input. With the platform out of level, a component of gravity is sensed in the platform plane. The platform is torqued to null out this acceleration. The errors tend to be very small; however, and usually a few minutes are required to sufficiently null out the error. [Ref. 38:p. 2.37-2.38]. For fine gyrocompassing, as the earth rotates, the platform is torqued to maintain the orientation perpendicular to local gravity (as explained earlier). This torquing is performed based upon knowledge of the orientation of true north. An error in the true north reference will cause the platform to be torqued around the incorrect axis, will result in the acceleration due to gravity being sensed in the platform and can in turn be used as an error signal similar to the fine leveling process described above. [Ref. 33:p. 35-36]. The process can take up to 10 minutes in many systems.

As is obvious from the description of the leveling process, the direction of local vertical must be known precisely to perform the procedure. In addition, the direction of true north relative to the erroneous axis about which the platform is torqued during the gyrocompassing process must remain fairly constant over long periods for the process to be performed. For this reason, the INS alignment and initialization process is usually performed while the aircraft is being started and before aircraft taxi. If the aircraft must be moved before the alignment and initialization is complete, the process must be suspended and then re-initiated when the aircraft is no longer moving. Using this technique fixes the local vertical vector relative to the aircraft (assuming the aircraft is on a level surface) and provides a steady true north reference between aircraft moves. This is by far, the simplest and most accurate method.

Ship-based aircraft pose a particularly difficult problem since their position changes, as does aircraft attitude relative to local vertical, as the ship pitches, rolls, yaws and moves across the earth. These aircraft INSs require a complicated, continuous input of the ship position and orientation parameters while the alignment is performed. This method requires special hardware and more alignment and initialization time than shore based methods.

Although much less accurate and much more time consuming, an alignment and initialization can usually be performed while airborne. An airborne alignment may be required due to an airborne system failure or following a rapid alert type launch where ground initialization and alignment may not be allowed due to time constraints. Airborne alignment and initialization usually requires an outside source of reference velocity (such as a doppler radar system), a source of precise aircraft position and long periods of straight and level flight. The results of airborne alignments are almost always much less accurate than the shore or ship based alignments.

While the alignment is taking place, the operator is usually provided with a status indicator of the alignment stage and thus a feel for how much longer the alignment will take. This status indicator and subsequent alignment complete indicator is essential since the long period required for INS alignment is often the limiting factor in aircraft alert response. A typical method is to provide a countdown of numbers with alignment complete indicated by a zero. In addition, fault discretes are provided to indicate various states of INS operation as well as BIT detected faults.

3.1.2.7. Inertial Navigation System Augmentation

An augmented INS uses some outside source to update some number of INS parameters following the initial alignment. To completely initialize the system and null out all errors and drift rates; all position, velocity and platform orientation parameters would have to be updated simultaneously and precisely. A full update is rarely possible in a tactical system. Most update only the aircraft position. The effect is to zero out position errors, leaving the error drift rate as it was before the update. [Ref. 38:p. 2.40].

The sample INS system, to be used for the remainder of the discussion, is augmented by visual flyover, radar, TACAN and OMEGA updates. In flyover updates, the pilot identifies a visual point of known latitude and longitude (which is entered into the INS computer) such as a surveyed tower. The pilot then flies over the point, visually marks on top, and commands an update. The INS position then changes to the entered latitude and longitude and navigation begins as before from the new latitude and longitude. In the radar update method, a radar target of known latitude and longitude is identified and entered into the INS computer. The radar cursors are then used to designate the point on the radar screen and this radar derived position, offset by the radar bearing and range, is used to re-initialize the INS position in a manner similar to the visual flyover. In the TACAN update, the TACAN bearing/range and known TACAN position are used in a manner similar to the radar update to re-initialize the INS position. Finally, in an OMEGA update, the OMEGA latitude and longitude are used as a direct replacement for the INS latitude and longitude. In all of these cases the drift rates that contributed to the initial errors are typically still present, requiring further updates.

3.1.2.8. Characteristic INS Errors

A list of INS error sources are provided below. Some of these errors are constant, some increase with time (linearly, exponentially, etc.) and some oscillate at the Schuler cycle frequency (84.4 minute cycles) or at the earth rate frequency (24 hour cycles). [Ref. 38:p. 3.3-3.5].

<u>Gyroscope Errors</u>
Accelerometer Error Output
Drift Rate
Output Bias
Torquing Error
Scale Factor Error
Nonlinearity
Misalignment

<u>Gimballed-Platform Error</u>
Acceleration-Induced Error
Structural Misalignment
Mass Unbalance
Vehicle Motion Isolation Inadequacies

<u>Accelerometer Errors</u>
Output Bias
Scale Factor Errors
Cross-Acceleration Errors
Nonlinearity
Misalignment

<u>Computer and Software</u>
Gravity Model Errors
Sensor Compensation Error
Analog to Digital Conversion Errors
Truncation and Round-off Error
Computational Algorithm Approximations

<u>Initialization, Update, Gyro-compassing and Damping Errors</u>
Position and Velocity Errors
Platform Alignment Errors

All of these errors are statistically uncorrelated [Ref. 38:p. 3.5] and when enough significant sources of error are present for an individual INS, the sources and their contribution to the total error cannot easily be determined. Sometimes a few sources are dominant and the individual sources can be identified by their characteristic error plots. Four are of particular importance because of their magnitude and the frequency with which they occur.

As was noted earlier, a platform leveling error will excite a cyclic error that oscillates at the Schuler cycle period. For a misalignment about the east-west axis, a north position error will be noted (latitude). For a misalignment about the north-south axis, an east position error will be noted (longitude). [Ref. 38:p. 3.5a]. For a constant platform leveling error, the maximum error will remain constant. As the leveling errors increase, so will the maximum error excursions in position. An initial error in aircraft latitude position will cause an oscillation in the north-south position error at the earth rate, with a 24 hour period. [Ref. 38:p. 3.5b]. An initial error in the true north reference, whether in a north seeking or wander azimuth system, will cause a combined effect. An oscillatory error will occur at the earth rate with a 24 hour period; however, the oscillation will be about a linearly increasing average error. The magnitude of the oscillation and the slope of the linearly increasing "zero point" of the oscillation will depend upon the magnitude of the north reference error. [Ref. 38:p. 3.5c] Finally, the INS azimuth gyro will tend to drift from the initial true north reference resulting in a north position error. This effect is characterized by a non-linear error of increasing slope. [Ref. 38:p. 3.5d].

3.1.3. OMEGA

3.1.3.1. Theory

OMEGA is a radio navigation, position fixing system, that compares the Very Low Frequency (VLF) signals from pairs of ground stations to determine an ambiguous [Ref. 64:p.1] range difference between pairs. There are eight stations as described below in table III [Ref. 64:p.1]:

The VLF frequencies used by the OMEGA system range between 9 and 14 Kilohertz (KHZ). Figure 8 depicts the transmission pattern of the station signals. The patterns repeat every 10 seconds. The individual station location is depicted to the left, the pulse widths and transmission gap widths are above the depiction of the trains in units of seconds and the frequency of each pulse is beneath the depiction of the pulses and are provided in units of KHZ. [Ref. 64:p.7].

The transmission pattern of the individual stations are very precisely synchronized using cesium standard clocks. [Ref. 64:p.2]. It is this highly precise, synchronized time that enables OMEGA to operate. In addition to being synchronized in time, the transmitted signals are also synchronized in phase. When an OMEGA receiver picks up two OMEGA signals transmitted at the same frequencies they are saved and compared to determine the phase relationship. The pairs of stations chosen for this comparison are generally those for which the OMEGA receiver lies as close as possible to a line drawn between the two stations (baseline). Figure 9 shows how position is determined for the very simple case of two stations separated by a baseline length of 1/2 wavelength.

Table III: OMEGA GROUND STATIONS

Station	Letter Designation	Coordinates
Norway	A	66° 25′ 12.62" N 013° 08′ 12.52" E
Liberia	B	06° 18′ 19.11" N 010° 39′ 52.40" W
USA: Oahu, Hawaii	C	21° 24′ 16.78" N 157° 49′ 51.51" W
USA: La Moure, North Dakota	D	46° 21′ 57.29" N 098° 20′ 08.77" W
France: La Reunion	E	20° 58′ 27.03" S 055° 17′ 23.07" E
Argentina	F	43° 03′ 12.89" S 065° 11′ 27.36" W
Australia	G	38° 28′ 52.53" S 146° 56′ 06.51" E
Japan	H	34° 36′ 52.93" N 129° 27′ 12.57" E

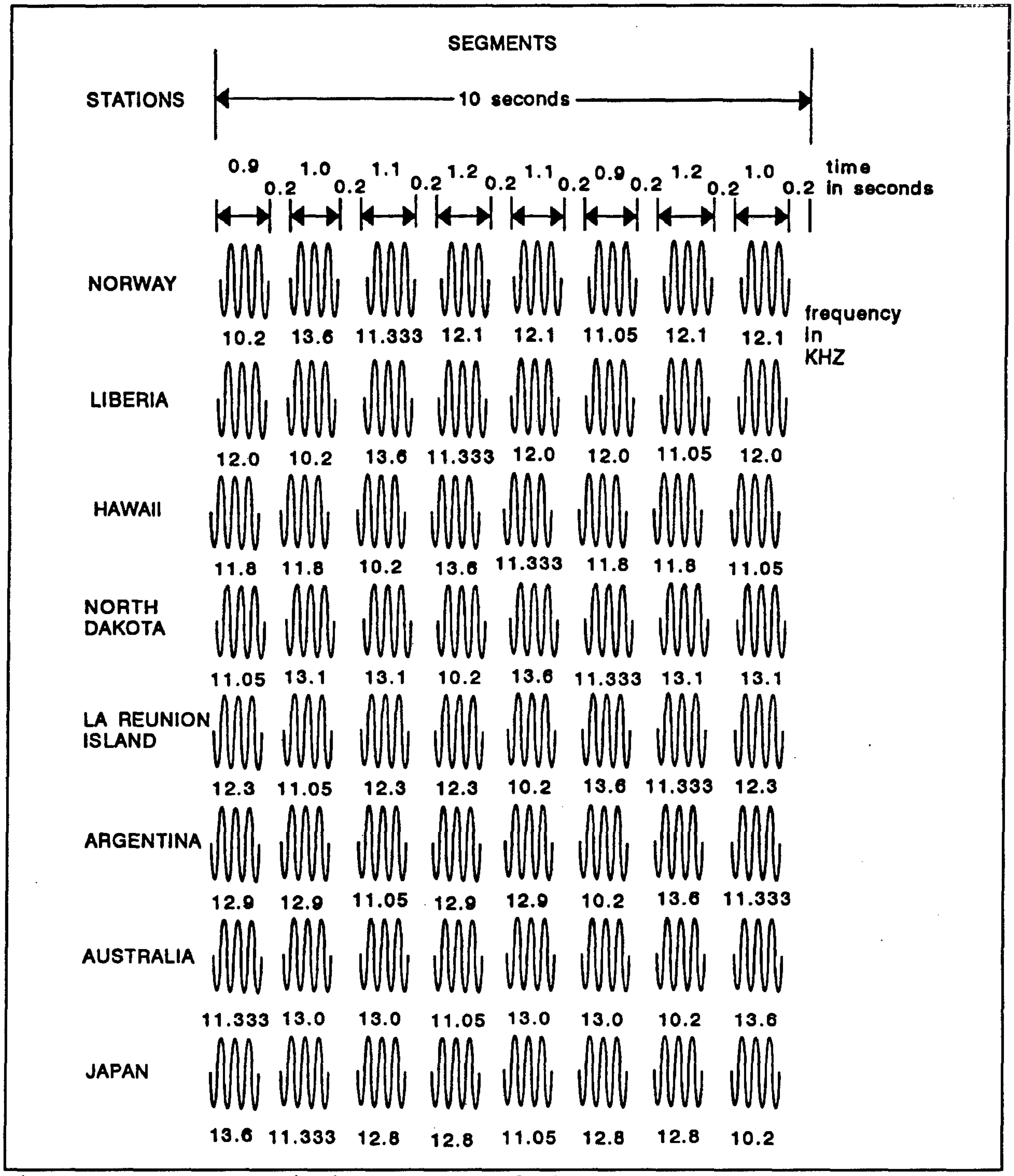


Figure 8: OMEGA Transmission Format [Ref. 27:p.7]

Since the velocity of propagation is relatively constant and the wavelength for a given frequency is known, the distance between stations, along the baseline, can be found from the phase of the signal at that point; again, for the simple case where the transmitters are separated by 1/2 wavelength. If the difference in phase is found, a locus of points, describing a hyperbola, are defined where the difference in phase between the signals is a constant. OMEGA is thus a hyperbolic navigation system.

In reality, the wavelength of the signals is only 16 nm (at the 10.2 KHZ frequency) and the stations are actually

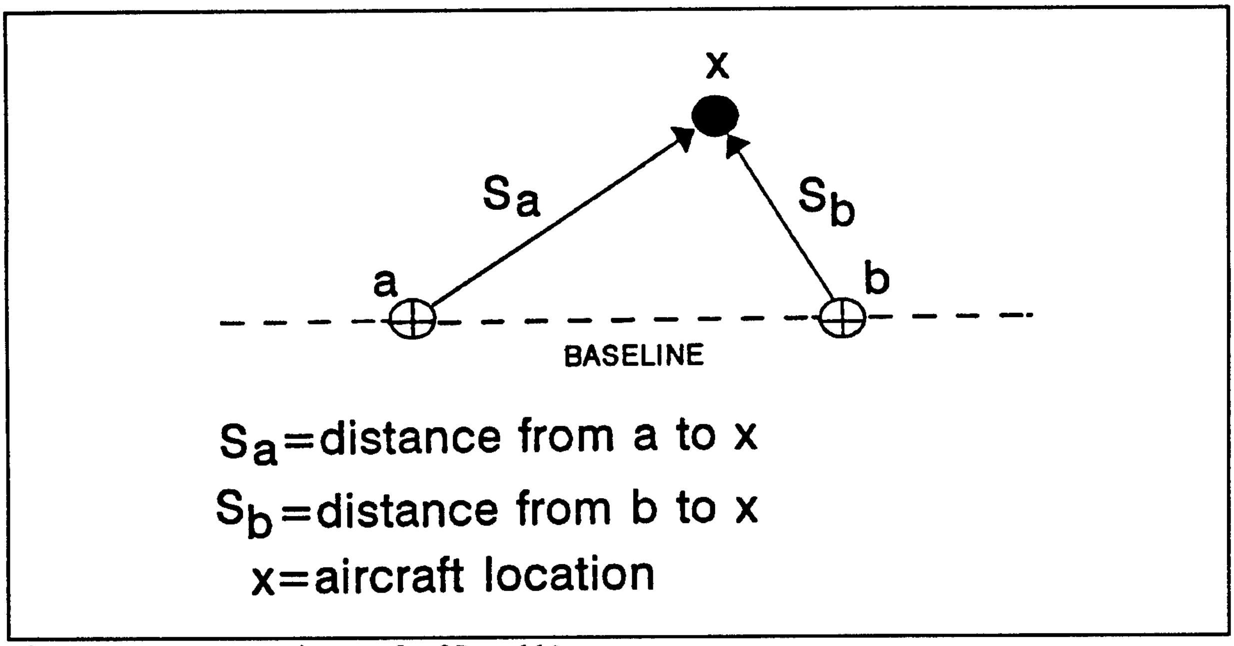


Figure 9: OMEGA Fix [Ref. 27:p.11]

separated by thousands of miles. This means that the hyperbolic loci of points are ambiguous at each 1/2 wavelength for the frequency used. [Ref. 64:p. 11]. The area between the zero phase difference (every 180° of phase shift) hyperbolic curves for each station pair are called lanes. The distance between lanes expands as the loci move away from the baseline. [Ref. 64:p.13]. The effects of the ambiguity can be partially mitigated by analyzing the phase difference of several of the frequencies transmitted by the same pair of stations. Analysis of the beat frequencies allows the use of lanes that are ambiguous at approximately every 144 miles. The exact width depends upon the wavelengths in question. [Ref. 64:p. 13-17].

Since some degree of ambiguity exists in either case, some method is required to determine the correct lane. Commonly, the technique used is to initialize the system at a beginning position (generally a latitude and longitude) and then to simply count the crossings of the zero phase difference points that define the lane edges. [Ref. 64:p. 13]. This function is automatic in airborne OMEGAs and is usually accomplished by keeping track of the OMEGA derived position and dead reckoning between fixes. In this way, the position of the aircraft is known along a unique hyperbolic curve that crosses perpendicular to the baseline between the stations. By repeating the procedure for two pairs of stations, the crossing of the two hyperbolic lines can be used to define a fix. [Ref. 64:p.14]. Note that it is entirely possible to have two hyperbolas cross at two distinct points. This ambiguity can be solved by comparing the two positions to the approximate position used to keep track of lane ambiguities.

3.1.3.2. Accuracy

As was mentioned, the lane hyperbolas are perpendicular to the line connecting the stations in use (baseline) and due to their shape, separate as they move away from the baseline. Since the accuracy with which the phase shift can be measured is the same at the baseline as away from it, the band of accuracy of the hyperbola upon which the OMEGA can locate the aircraft expands as the aircraft moves off the baseline. This phenomenon is called Geometric Dilution Of Precision (GDOP). Luckily, the extremely long baselines used in the OMEGA system mitigate the GDOP effects greatly as long as the optimum ground stations are chosen.

One reason the VLF frequency range was chosen for OMEGA was the extremely long transmission ranges possible in this frequency band. When VLF waves are transmitted they tend to bounce off the bottom of the ionosphere and off the earth's surface. The effect is to duct the waves around the earth. Because of this, the characteristics of the two ducting surfaces can affect the OMEGA RF and thus the accuracy of the system. Generally, the propagation characteristics are fairly predictable; however, several perturbations can affect the transmission and must be accounted for. First, the altitude of the ionosphere is quite different between day and night. The night altitude is somewhat less predictable than the day altitude, accounting for a slight degradation in the night time OMEGA accuracy; however, both altitudes can be approximately accounted for in the programming of an automated OMEGA system. This phenomenon is known as the diurnal effect. Second, the transition line between night and day causes instabilities in the propagation pattern due to the changes between the day and night ionospheres. This effect can be mitigated through preference to station pairs that do not have a baseline currently intersecting the transition line and when still needed, by partial correction within the OMEGA software. [Ref. 64:pp. 17-18]. Third, variations in the transmission over different surfaces can affect propagation. Smooth water is a near perfect ducting surface while large ice masses at the polar caps can make the signal nearly unusable. The solution is to compensate for the propagation effects knowing the point of origin of the RF, the position of the aircraft and the terrain between. Since polar cap attenuation is so pervasive, stations providing directions of arrival over the poles are usually deselected. [Ref. 32:p. 1-30].

When the RF is radiated from the large OMEGA groundsite antennas, three paths, or modes, are possible. The first is the direct path between the station and the aircraft, the second immediately bounces off the ionosphere and then propagates to the aircraft and the third bounces off the ground and then propagates to the aircraft. The three modes can then interfere with each other. Fortunately, the skywave and groundwave RF are rapidly attenuated with the net effect that the interference is only a significant factor from minimum range to approximately 200 to 500 nm from the groundsite. The phenomenon is known as near station modal interference and is countered by simply deselecting the closer stations. [Ref. 11:p. 7]. Since VLF has excellent long range propagation characteristics, it is quite possible for the aircraft to receive RF from a groundstation via the long route around the earth as well as the direct route. The two signals then interfere with each other. The interference is rare when the station is within 8,500 nm of the aircraft; however, and so the problem is minimized by deselecting stations at very long ranges. [Ref. 32:p. 1-62].

The next two phenomenon to be discussed are Sudden Ionospheric Disturbances (SIDs) which are caused by X-rays emitted during solar flares, and Polar Cap Anomalies (PCAs) which are present only at high latitudes and result from high energy protons emitted from the sun that are drawn to the poles by the earth's magnetic field. These two phenomenon cannot be accurately predicted and thus cannot be accounted for within the OMEGA system. These errors can amount to as much as 8nm at the 10.2 KHZ frequency. [Ref. 64:p. 19]. These two effects are of short duration and rarely are a significant factor.

The final effect to be discussed here is caused by the relatively long integration period of the OMEGA system, that is, the time required for the OMEGA to update the position. The airborne OMEGA can require as much as two minutes to update the displayed position and as such usually requires dead reckoning between fixes. The OMEGA is then prone to the errors inherent in any DR system. [Ref. 38: p. 2.81]. Excluding the unpredictable SID, PCA and DR errors, the day time accuracy of the modern OMEGA system with automatic latitude and longitude determination/display and automatically applied correction tables is around 1 nm in the daytime and 2 nm at night [Ref. 38:2.82].

3.1.4. Tactical Air Navigation

3.1.4.1. Theory

TACAN provides relative, magnetic bearing and slant range in nm to a known ground station. The systems used for bearing and range are separate. TACAN bearing is found by comparing the phase relationship of a rotating antenna pattern and omnidirectional reference pulses. The antenna pattern is transmitted at the ground site and is in the shape of a cardioid that has a nine lobed pattern superimposed upon it. The entire pattern rotates at 15 HZ and thus the rotating maximum of the cardioid will pass a given bearing at a rate of 15 HZ and one of the nine lobes will pass the same bearing at a rate of 135 HZ. Simultaneously, an omnidirectional pulse train is transmitted each time the maximum of the cardioid passes through east. A second pulse train is transmitted each time any of the nine maximums pass through east. The envelope of the two superimposed sinusoidal signals (15 and 125 KHZ) are resolved by the airborne receiver. The phase of the two signals are then compared to the reference signals transmitted at the east position. The phase difference will be zero for the 15 KHZ signal only if the receiver is east of the groundstation. The phase difference will increase from 0 to 360° as the receiver is moved around the ground site clockwise. The 15 KHZ signal will provide an unambiguous bearing; however, the bearing is fairly inaccurate. The 135 KHZ signal provides the required accuracy but is ambiguous every 40°.

Each time one of the nine maximums crosses east, the corresponding pulse train reference signal is transmitted. As the receiver moves around the ground station, the phase shift between the 135 KHZ envelope and the reference will shift through 360° every 40° of rotation around the ground station. The 15 KHZ rough bearing is used to resolve the 135 KHZ ambiguity. Occasionally, the ambiguity is solved incorrectly and the TACAN will provide a bearing in error by multiples of 40°. This is known as 40° lockout. For bearing, TACAN uses line of sight propagation in two bands from 962 to 1024 and 1151 to 1213 MHZ, a maximum power out from the ground site of 1 to 20 KW and a maximum range of 300 nm from the ground station to the receiver. Bearing error is usually around 3.5° and results from site errors associated with ground and other reflections of the signals transmitted by the ground site and from errors associated with the airborne receiver. [Ref. 38:pp. 2.68-2.74].

Range from the ground station to the TACAN equipped aircraft is derived by measuring the time for an interrogation pulse to travel from the aircraft to the TACAN ground station and for a reply to return to the aircraft. The hardware is called Distance Measuring Equipment (DME). The airborne TACAN transmits an interrogation pulse pair consisting of 3.5 μsec pulses 12 μsec apart and at a frequency separated by 63 MHZ from the ground station reply frequency. The ground site receives the interrogation, holds it for a fixed period of 50 μsec, and then sends out a reply. Subtracting the set delay period, range can be determined directly, given the speed of propagation. Each ground site can handle 100 simultaneous users. As the number of users increases above this number, the 100 interrogators with the strongest signals are serviced.

Since all the reply signals are identical, two techniques are used to prevent the display of ranges based upon replies to other TACAN interrogators. First, a range tracker is used within the airborne TACAN unit, that rejects replies out of the expected window. Since it is still possible to have some number of aircraft at the same approximate range from the ground site and thus crossing within each other's range gates, the interrogators vary the PRF between 5 and 25 Pulses Per Second (PPS) to reduce the chance that the incorrect replies will fall in the tracked range gates. Establishment of the initial range tracker gate and subsequently the display of the first DME value can take from 1 to 20 seconds. To facilitate the initialization process, the PRF of the interrogation is increased to 150 PPS until range tracking is established. For ranging, the TACAN uses line of site propagation of airborne and ground site frequencies in the band of 1025 to 1150 MHZ, a power of 50 to 2000 W for the airborne equipment and 1 to 20 KW for the ground sites, and a usable maximum range of from 50 to 300 nm. Ranging accuracies vary from 0.1 to 3.0 nm. By far the largest contributor of error is the user equipment. [Ref. 38:pp. 2.65-2.67].

3.1.5. Missions

Although not as critical for navigation testing as for radar testing, a good knowledge of the intended mission of the navigation system is required to develop a proper test technique. For example, a knowledge of the intended operating area is useful in selecting the correct operating modes for a test INS to insure that time is not wasted testing modes that are likely not to be used. Many INSs use a special operating mode above 70° of latitude and if the aircraft is not expected to be flown above this latitude it could be a waste of time and money to take anything other than a cursory look at this function.

A knowledge of the intended mission duration is essential for development of test scenarios. For DR and integrated navigation systems, the airborne tests should be performed for at least a period as long as the expected mission duration. This is to ensure that the DR system's drift does not exceed the maximum allowable limits, even at the end of the mission. Mission relatable maneuvers need to be performed to ensure that normal mission g levels, maneuvering rates and aircraft attitudes do not adversely affect navigation accuracy. These maneuvers can affect the stability of an INS platform, exceed the dynamic range of the INS accelerometers or cause the fuselage to mask the antenna for a radio navigation system.

A thorough mission knowledge is required to understand the accuracy requirements of the system. The requirements for a system that must drop ordnance at given geographic coordinates and a system required for long range, overwater navigation are quite different. As with the radar test techniques, the navigation test techniques to be presented here require knowledge of the intended mission, since they are based upon the premise of qualitative testing in a mission relatable scenario and quantifiable data to support this assessment. If mission relatable experience is not present on the test team, then extensive research is required.

3.1.6. Navigation System Human Factors

As in the radar human factors section, no attempt will be made to completely cover the topic of ergonomics. As with radar systems testing, navigation system controls and displays testing must be performed while seated at the DEP and wearing a full set of personal flight equipment. The procedure for finding the DEP is explained in the radar theory section. The anthropometric measurements and the flight gear worn by the evaluator must be recorded.

3.1.7. The Flyover Method

The flyover method will be used as the primary means for determining the aircraft's actual dynamic (airborne) position. This position will be used as truth data. The technique is simple and requires a minimum of instrumentation. Preflight planning is important to this technique. Prior to flying the test, the evaluator must choose a number of surveyed landmarks to be used as flyover points. The landmarks must be easily found from the air, which usually means that the object used must be large compared to other features in the area and isolated from other landmarks. For instance, isolated towers are good choices in most terrains. Isolated road intersections in desert or plain areas are adequate. Distinct points of land, large sea navigation aids such as spider buoys or light houses and small, well defined river inlets are useful when doing testing near the coastline. The landmark must be discrete, that is, the pilot must not have to figure out which part of the landmark to fly over. As an example, an island is generally too large to use as a flyover point; however, a point of land on the northern edge of the island may be adequate.

As important as finding and isolating the specific feature, is knowing the exact latitude and longitude of the point. The location must be known with an accuracy commensurate with the test technique. For the flyover technique, a latitude and longitude position with an accuracy of around 100 feet is sufficient. When choosing the points, the evaluator can search a TPC of the test area and choose landmarks as shown on the chart. The surveyed positions are then derived from the listing of vertical obstructions, reference 68. These surveyed positions are of adequate accuracy for the flyover technique.

Flying the technique requires the pilot to first find the landmark. Onboard sensors such as navigation or surface search radar, electro-optical systems, as well as the navigation system under test can be used. Prior to flyover, the pilot must acquire the landmark visually. The technique involves flying directly over the target and recording data. The exact data differs depending upon the system under test; although, the identification of the landmark and the displayed position provided by the navigation system under test at the time of overflight is always required. Optimally, the pilot should fly directly over the target; however, if unable, the direction to the target and the displacement at the time of Closest Point of Approach (CPA) should also be recorded. The accuracy of the method is affected by the technique of the pilot and the flyover altitude. Generally, for a pilot experienced in the technique, the accuracy will be about one half of the altitude above the target. An altitude of between 200 and 2000 feet above the landmark is typical. [Ref. 38:p. 4.5]. The technique is flown identically for both position fixing and DR navigation system testing.

3.2. NAVIGATION SYSTEMS TEST TECHNIQUES

3.2.1. Preflight and Built in Tests

3.2.1.1. Purpose

The purpose of this test is to assess the suitability of the navigation system preflight and turn on procedure and the BIT to quickly and easily bring the navigation system on line and insure an operating system once airborne.

3.2.1.2. General

As airplanes become more expensive, fewer and fewer will be available to accomplish each mission, amplifying the loss of individual airplanes to inflight failures. Quick, accurate ground preflight tests are essential to determine system status while repair can still be affected. This requirement is particularly important for navigation systems included in highly integrated, modern aircraft since nearly all systems require an accurate navigation input to function correctly. Quick response/alert time is also important and so these checks must be expeditious and must allow the operator to prepare for the mission with a minimum of distractions. Limited airplane availability also implies the need for quick turn arounds to send the same aircraft out for successive missions.

Many aircraft systems can be turned on after the aircraft is airborne; however, this is often not the case for navigation systems since the pilot must begin navigating at takeoff, particularly on night and bad weather flights. For INS systems, the preflight and turn on sequence must be performed serially before the initialization and alignment process. The INS initialization and alignment process is often the longest procedure required to get the aircraft ready for flight and so the serially dependent preflight and turn on procedure must be as expeditious as possible. Radio navigation aids, such as OMEGA or GPS, require preflight and turn on before the system can begin acquiring the stations and integrating to a solution, also requiring a rapid preflight and turn on procedure. Although the BIT can often be performed during the initialization and alignment process in INS systems and during acquisition and integration for radio navigation systems, the BIT results must be known as accurately and quickly as possible so that failures can be repaired and the long process begun again. The entire procedure must be accomplished safely and thoroughly before a hurried combat mission.

3.2.1.3. Instrumentation

A stop watch and data cards are required for this test. A voice tape recorder is optional.

3.2.1.4. Data Required

Qualitative comments, time to complete the preflight/turn on and time to complete the BIT are required. A record of BIT indications is required.

3.2.1.5. Procedure

Perform a normal navigation system turn on before each test flight using the published system check list. Note the time for preflight and turn on up to the point of initialization and alignment. Perform a preflight BIT, noting the total BIT time and indications. Note any correlation between the BIT indications and the navigation system's operation. Perform a complete check of the failure indications on the ground. Make qualitative comments as appropriate.

3.2.1.6. Data Analysis and Presentation

The time and complexity of the navigation system preflight and turn on procedures should be related to the expected alert launch time requirements and the overall operator workload during the alert launch. Note other serial requirements following the preflight, turn on and BIT before the system can provide airborne navigation and relate them to the requirement for accurate navigation information immediately following takeoff during night and bad weather flying. The BIT times and the amount of operator interface required to perform the BIT should be assessed in the same scenario. Clarity of the BIT indications should be related to the cockpit environment. The BIT indications should be related to actual navigation system degradation and verified by ground technicians. Erroneous BIT false alarms should be noted and related to the probability of unnecessarily missed sorties.

3.2.1.7. Data Cards

Sample data cards are presented as cards 34 and 35.

CARD NUMBER ___

NAVIGATION SYSTEM PREFLIGHT/TURN ON

CLARITY OF CHECKLIST INSTRUCTIONS:

LOGICAL SEQUENCE OF CHECKLIST:

THOROUGHNESS OF CHECKLIST:

TOTAL PREFLIGHT/TURN ON TIME________________

DEPENDENCY OF OTHER AIRCRAFT SYSTEMS UPON THE NAVIGATION SYSTEM PREFLIGHT/TURN ON:

Card 34: Navigation System Preflight/Turn On Data Card

CARD NUMBER ___

NAVIGATION SYSTEM BUILT IN TESTS

INITIATION PROCEDURES:

RUN/FINISH INDICATIONS:

EFFECTS OF THE BIT UPON THE INITIALIZATION/ALIGNMENT (i.e., SERIAL OR CONCURRENT):

BIT FAILURES AND QUALITATIVE FUNCTIONAL ASSESSMENT OF THE NAVIGATION SYSTEM/RESULTS OF GROUND MAINTENANCE CHECKS:

Card 35: Navigation System Built In Test Data Card

3.2.2. Controls and Displays

3.2.2.1. Purpose

The purpose of this test is to assess the suitability and utility of the navigation controls and displays for the assigned mission as an interface between the operator and the navigation system.

3.2.2.2. General[8]

As good as many new systems are at determining the position, rates and orientation of the aircraft and in providing recommended steering information, they have failed if the operator is not presented with a usable display of navigation parameters or if the operator is not given adequate controls to operate the system. The controls and displays must be usable in every conceivable flight regime, ambient lighting condition, weather condition, and by aviators with the range of anthropometric measurements for which the system was designed to operate. For the modern fighter or attack airplane, this is usually all weather, day or night, around +9 to -4 gs, for the 3 to 98 percentile groups, and in a realistic tactical environment filled with urgent decisions demanding the aviator's attention. The controls and display should require an absolute minimum of operator input or interpretation and the information imparted and required from the operator should be a minimum and precisely what the aviator needs to execute the current phase of flight. The requirement to tailor the information provided to the phase of flight is particularly important for a navigation system.

Controls should be easily manipulated wearing the proper flight clothing. The range of control (both the physical range of movement of the knob, dial, lever, etc. and the range of effect that the control has upon the navigation system) and sensitivity should be compatible with the expected flight regime. Controls that require manipulation while airborne should be reachable from the DEP, particularly if they must be activated in a combat environment. As an example, the controls necessary to perform a visual position update must be reachable while performing high g evasive maneuvers ingressing to a target and while maintaining a body position ready for safe ejection. The operative sense must be correct. This means that the direction of activation should conform to the standards of common sense (turn the knob to the right to turn on the system) and to the standards set in references 15 and 16 (which for the most part merely put on paper the standards of common sense). The operation of the controls should be clear, requiring a minimum of operator concentration and attention. This leaves the operator free to make tactical decisions.

The controls should also be placed in logical functional groups, reducing the area of scan required to check the navigation system set up. The navigation system controls should be integrated well into the cockpit. This means that the navigation system controls should operate harmoniously with the other controls within the cockpit and without hindering the simultaneous operation of other airplane systems. Integration must be evaluated during a mission relatable workload and while simultaneously operating all the other airplane systems. This is important since navigating should take a minimum of operator concentration and time, leaving the operator free to perform other tasks, such as selecting targets and evading surface to air missiles.

Lastly, the controls should provide good tactile feedback. For example, detents should provide the proper amount of "click" and all the knobs shouldn't feel exactly alike when reaching for a navigation control with eyes on the radar scope. Applying a little common sense and manipulating the controls in a mission relatable environment usually uncovers most of the control human factors violations.

Many modern aircraft have a large number of the avionics controls included in the HOTAS format, allowing manipulation without releasing the throttle and stick. These implementations have their own human factors challenges. Typical problems include the mounting of too many controls on the available area, appropriate control sensitivity across broad height conditions and tactile feedback considerations.

The navigation displays should be clearly visible from the DEP in bright daylight as well as complete darkness. In bright daylight, the display must be

[8] For an introduction into controls and displays human factors, see references 20, 54 and 73.

usable under all conditions of glare including sunlight directly over the operator's shoulder onto the display (a particularly serious problem for most displays). In the dark, the display should not be so bright that it distracts the operator or affects his night vision. A good range of brightness control that integrates harmoniously with the rest of the cockpit is required. In many cases, navigation information is integrated into other tactical displays. Heading markers, course, steering, range and time to go to waypoints etc. are often integrated into HUD and radar displays. The navigation information must be harmoniously integrated into these displays providing clear and concise navigation cues without degrading the other uses of the displays.

The display must refresh itself quick enough so that the symbology and alphanumerics present an even and continuous display without noticeable flicker. Analog displays and digital representations of analog displays such as compass cards, ownship on a geostable tactical display etc. should update smoothly as the simulated compass card rotates or the own aircraft symbol transits across the background. Alphanumerics must be clear and legible. The messages should be short and easily understood without excessive coding or operator interpretation. The information displayed to the operator, including symbols and alphanumerics, must be sufficient for the current phase of flight while at the same time not overloading the operator with information. This usually requires tailoring the display to the specific attack mode/mission/phase of flight, that is currently being used. The display should be assessed for the information load in a mission relatable scenario to determine its utility as an aid in the combat environment as well as in normal Instrument Flight Rules (IFR) navigation.

It is unlikely that a display compatible in size, weight, power and cooling requirements with a tactical airplane will be built in the near future that has too large of a usable display face. Thus, the display should be evaluated for size in a relatable mission environment, accounting for this element of realism. The display should be positioned in a location suitable for the mission. As an example, the course to target cursor, range/time to target etc., should be placed high in the cockpit, along with the radar and/or FLIR display, so that the operator can scan his sensors, recommended vectors and also visually search for the target. As with controls, display human factors problems typically surface by applying a little common sense while using the system in a mission relatable scenario.

3.2.2.3. Instrumentation

A tape measure and data cards are required for this test. A voice recorder is optional.

3.2.2.4. Data Required

Record qualitative comments, evaluator's anthropometric data and a list of personal flight gear worn. The location and type of the navigation information displays should be recorded for integrated systems that provide navigation information in several locations (HUD, radar display, Electro-Optic (EO) display, etc.). Legibility and readability of the navigation information in all display locations should be recorded. The location of the display from the DEP should be measured if a qualitative problem is noted. Reach length of the controls that are beyond the operator's reach while seated at the DEP during any mission relatable scenario should be recorded. The utility of the provided information and information load (Is too much information provided?) should be recorded during mission relatable scenarios.

3.2.2.5. Procedure

Find the DEP as outlined in the radar theory section. All ground and airborne tests should be performed while at the DEP and wearing a complete set of flight gear. Perform a system turn up on the ground outside of the hangar in a range of ambient lighting conditions (bright daylight to darkness which may be simulated using a canopy curtain). Manipulate all controls noting the factors discussed above. Measure the display usable area. Evaluate the display for the factors discussed above. Note and measure the position and reach length to all controls and displays that pose a visibility or reach problem while seated at the DEP. During airborne testing, manipulate the controls and make qualitative comments during mission relatable IFR navigation scenarios and mission relatable attacks and intercepts. Take particular note during extremes of ambient lighting for displays and during high g maneuvers for controls. Confirm the results of the ground checks for reach and visibility while airborne. Check the extremes of the control limits and sensitivity. Repeat the evaluation for each test flight.

3.2.2.6. Data Analysis and Presentation

Present a table of the operator's anthropometric data and the personal flight equipment worn during the tests. Present the seat position as the number of inches from the bottom of the seat travel. Relate the sensitivity of the controls to the tactical environment in which they are to be used. For example, a fighter's HUD brightness potentiometer knob may be too sensitive to use under moderate g or turbulence making it unusable during intercepts and ACM. Relate the accessibility, placement and grouping of the controls under mission relatable conditions. A navigation update selection must be readily accessible while maneuvering evasively inbound to a target and looking outside for surface to air missiles. Relate the control clarity, operative sense and tactile feedback to a multiple threat, combat scenario requiring the operator to make quick tactical decisions. If ambient lighting affects the display in any way, relate this to the limits of the possible combat environments. The displays should update smoothly as the aircraft maneuvers and transits.

Relate the information load presented the operator to the combat scenario discussed above and evaluate whether the needed information is present and whether too much information is cluttering the display. This information can include analog representations of navigation information, alphanumerics or symbols. This concept is closely related to the size of the display face usable area. A large scope can present more information without cluttering the display and requires less concentration to read and evaluate. The refresh rate should be related to the concentration required to interpret a jittery display. The display position should be evaluated for the type of information involved, the eye position required for using the display and the display position's effect upon scan.

3.2.2.7. Data Cards

Sample data cards are presented as cards 36 and 37.

CARD NUMBER ___

ON SYSTEM CONTROLS

CLARITY OF OPERATION:

ACCESSIBILITY (MEASURE REQ ACH IF A PROBLEM):

OPERATIVE SENSE:

ADJUSTMENT SENSITIVITY:

RANGE OF ADJUSTMENT:

TACTILE FEEDBACK:

FUNCTIONAL LOCATION/GROUPIN IF A PROBLEM):

INTEGRATION:

Card 36: Navigation System ta Card

CARD NUMBER ___

NAVIGATION SYSTEM DISPLAYS

[PERFORM IN BRIGHT DAY TO DARKNESS]

LIST THE LOCATION AND TYPE OF NAVIGATION INFORMATION:

LOCATION QUALITATIVE COMMENTS (MEASURE THE LOCATION IF A PROBLEM):

CONTRAST/BRIGHTNESS/GAIN CONTROLS (RANGE OF EFFECTIVENESS):

GLARE (BOTH FROM OUTSIDE AND INSIDE COCKPIT LIGHT SOURCES):

REFRESH RATE QUALITATIVE COMMENTS:

LOCATION OF THE SYMBOLOGY/ALPHANUMERICS UPON THE MULTIFUNCTION, INTEGRATED DISPLAYS:

INTERPRETATION OF SYMBOLOGY/ALPHANUMERICS:

INTEGRATION:

Card 37: Navigation System Displays Data Card

3.3. INERTIAL NAVIGATION SYSTEMS TEST TECHNIQUES

3.3.1. Initialization and Alignment

3.3.1.1. Purpose

The purpose of this test is to assess the INS initialization and alignment procedures for their utility for quickly reaching a full navigation status with a minimum of operator time and attention and the effect that these procedures have upon the set up sequence of other aircraft systems.

3.3.1.2. General

The INS initialization and alignment process is described in the navigation theory section. Initialization includes providing the INS with position and orientation inputs from which to reference the alignment. Alignment involves first leveling the platform and then orienting the true north axis to the geographic true north. Alignment is usually serially dependent upon initialization. The set up of other aircraft systems is sometimes partially dependent upon the presence of an INS alignment. As an example, geostable tactical displays require navigation input to operate. While alignment is taking place, the pilot will have many other tasks to perform, such as turning on other systems, starting the aircraft, attempting to obtain tactical SA, or putting on his flight gear and strapping into the aircraft seat. A quick and easy alignment process requiring a minimum of operator inputs and attention is essential.

Several factors can affect the initialization and alignment process. navigation control and display issues, addressed earlier can affect the time and effort required for the entry of the initialization parameters. Outside air temperature can affect alignment time. The colder the temperature of the INS, the longer the alignment will take. Motion of the aircraft can slow the alignment process. Actually moving the aircraft, whether by taxiing or towing, usually requires suspending the alignment with an additional penalty of time as the process is resumed. Alignment latitude can affect the alignment time. An alignment often will take longer at higher latitudes, with a significant delay above 70° latitude. Ship based alignments usually take 50% to 100% longer than shore based alignments. Most systems require four to ten minutes for the shore based initialization and alignment procedure. A wide variance of times can be obtained depending upon the factors listed above and so it is important to carefully record the conditions of the alignment. Since the alignment process takes a significant amount of time, a status indication should be provided to give the pilot an indication of the time left to a complete alignment and to provide feedback that the process is proceeding normally.

Ideally, the INS should be checked over the entire range of expected alignment conditions. Checking all conditions is rarely possible. A wide range of temperature conditions can require much travel, time, or expensive test chambers. Testing the alignment times over a variety of locations also requires expensive travel. This test procedure will be performed at the given test location and current atmospheric conditions providing a spot check of one possible condition. If a choice is available; however, it is always best to test at the expected operational conditions and secondarily at the extremes of the expected range of parameters. For this technique, ship based alignments will not be discussed. The ship based test technique is essentially the same except that automatic recording of the continuously changing position and orientation parameters is required.

The sample system includes an airborne alignment mode. An airborne alignment may be required if an alert launch has to be made before a ground alignment is complete, or after the loss of alignment with the aircraft airborne. An airborne alignment can take much more time than a ground alignment. A typical alignment may take twenty minutes or more. Typically, the alignment is begun by initializing the latitude and longitude to the correct position. This is often done by overflying a known position and initializing at the instant of the flyover. Most INSs require the aircraft to be flown straight and level as much as possible during the airborne alignment procedure. The airborne alignment test is nearly identical to the dynamic non-maneuvering position accuracy test and so a discussion of the procedure will be deferred until that section.

3.3.1.3. Instrumentation

A stop watch, thermometer (suitable for measuring outside air temperature) and data cards are required for this test. A voice recorder is optional.

3.3.1.4. Data Required

Record the time required to input the initialization parameters. Record qualitative comments concerning the ease and complexity of the data entry. Note if the initialization process interferes significantly with the start up and turn on procedures for the entire aircraft. Record the surveyed latitude and longitude of the aircraft, the actual heading of the aircraft during alignment (if available via an independent source such as a calibrated compass alignment rose), local magnetic variation and outside air temperature. If a compass rose is not available, record the surveyed alignment position, magnetic compass heading (with deviation applied) and magnetic variation. Record a complete description of aircraft motion during the alignment. For the interrupted alignment, record the elapsed time at interrupt, resumption of the alignment and a complete description of the aircraft movement. Include the new surveyed location and aircraft heading. At the completion of the alignment, record the INS displayed latitude and longitude, magnetic heading, true heading, magnetic variation and the total time for the alignment. Note qualitative comments concerning the utility of the INS alignment status indications including the alignment complete indication.

3.3.1.5. Procedure

Most airfields have a surveyed compass rose which is used for calibrating installed magnetic compasses. The center of the rose is accurately surveyed in latitude and longitude and magnetic headings are marked around the circumference of the rose. When possible, the alignment should be performed at the surveyed rose to provide accurate position and heading truth data. When a compass rose is not available, perform the alignment at any other surveyed location. Most hangars have surveyed parking slots on the ramp. In this case, an estimate of aircraft heading after alignment can be obtained using the magnetic compass, or some other portable magnetic heading source, with deviation applied. Local area magnetic variation should be obtained from published field charts, approach plates, en route charts, TPCs, etc.

Tow the test aircraft to the local compass rose and record the surveyed position, heading and magnetic variation. If a compass rose is not used, record the surveyed alignment location, the magnetic heading as displayed on the back up magnetic compass with deviation applied and the magnetic variation. Allow the INS to remain OFF for at least one hour before beginning the test to allow the components to cool to ambient temperature. Record the outside air temperature.

Using the procedure published for the INS, perform an INS initialization. Record the time required for initialization along with qualitative comments concerning the ease of the initialization procedures and the extent to which initialization distracts the pilot from turning on the entire aircraft. Following the initialization procedure, begin the alignment, starting the stopwatch as the alignment begins. As the alignment progresses, note the quality of the alignment progress status indicators and of the alignment complete indication. When the alignment is complete, note the total elapsed time, the indicated magnetic and true aircraft heading and the magnetic variation. Completely describe any aircraft motion during the alignment process. Repeat the initialization and alignment test before each test flight.

At least one interrupted alignment should be performed. Begin the alignment process at any surveyed point and then tow or taxi the aircraft to the surveyed compass rose to complete the alignment process. Record the parameters described above at both the first and second location. Note the elapsed time at interrupt and again when the alignment is resumed.

3.3.1.6. Data Analysis and Presentation

Relate the time required to perform the INS initialization, the complexity of the procedure and the overall operator intensity as a distraction to the pilot as he or she attempts to turn on other systems, straps into the aircraft, starts the engines and gains SA. Compare the initialized aircraft position at the start of the alignment (input by the operator) to the position at the time the alignment is complete. There should be no drift during the alignment process. Apply the actual aircraft heading on the compass rose and the local magnetic variation to equation (21) to obtain true heading. Where a compass rose is not used, apply the magnetic back up compass heading with deviation applied and local magnetic variation to equation (21) to obtain true heading. The accuracy of the truth data will be degraded. Compare the true heading, magnetic heading and magnetic variation provided by the INS at the time of the alignment to the actual values and relate the difference to the quality of the alignment, the effect that inaccuracies will have upon positional drift and the utility of INS headings for accurately navigating in a mission relatable ingress and attack.

Relate the quality of the status indicator, including the alignment complete indication, as a guide to how long the alignment has left to complete, as a source of confidence that the alignment is progressing normally and as an indicator that the aircraft has an operating navigation system with which to launch. Relate this to the time requirements and stress of an alert launch. Compare the alignment time to the time requirements of an alert launch and to the specification at the ambient temperature recorded during the test. If extreme variation in the alignment time and quality is noted during alignments where aircraft motion is a factor (for instance while maintenance personnel are climbing on the airplane) relate it to the requirement for pre-flight trouble shooting before aircraft launches. Compare the time for a suspended alignment less the actual time the alignment was suspended, to the time for an uninterrupted alignment. Relate any extreme variation to the requirement to occasionally move aircraft on a crowded ramp during a mass alert sortie.

3.3.1.7. Data Cards

Sample data card are provided as card 38.

CARD NUMBER ___

INITIALIZATION AND ALIGNMENT

ALIGNMENT LOCATION __________

____

ALIGNMENT HEADING __________

MAGNETIC VARIATION __________

[ALLOW THE AIRCRAFT TO COLD SOAK FOR ONE HOUR. PERFORM A NORMAL INS INITIALIZATION.]

INITIALIZATION EASE/COMPLEXITY/EFFECTS UPON OTHER TURN ON AND START PROCEDURES:

INITIALIZATION TIME __________

[START ALIGNMENT. START STOP WATCH.]

OUTSIDE AIR TEMPERATURE __________

COMPLETELY DESCRIBE ANY AIRCRAFT MOVEMENT:

[IF THE AIRCRAFT IS TURNED OR TOWED, NOTE THE TIME OF THE SUSPENDED ALIGNMENT AND THE TIME OF THE RESTART.]

SUSPENDED __________

RESTART __________

DESCRIPTION OF AIRCRAFT MOVEMENT DURING SUSPENDED ALIGNMENT:

Card 38: Initialization and Alignment Data Cards

INITIALIZATION AND ALIGNMENT

FOR THE NEW AIRCRAFT LOCATION:

ALIGNMENT LOCATION __________

____

ALIGNMENT HEADING ___________

MAGNETIC VARIATION __________

TIME TO COMPLETE THE ALIGNMENT ___________

QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE ALIGNMENT STATUS AND THE ALIGNMENT COMPLETE INDICATORS:

WHEN ALIGNMENT COMPLETE:

DISPLAYED LOCATION __________

____

DISPLAYED MAGNETIC HEADING ___________

DISPLAYED TRUE HEADING __________

DISPLAYED MAGNETIC VARIATION __________

WERE OTHER SYSTEMS/PROCEDURES WAITING ON THE ALIGNMENT? IF SO, DESCRIBE:

Card 38: Initialization and Alignment Data Cards (Continued)

3.3.2. Static Position Accuracy

3.3.2.1. Purpose

The purpose of this test is to measure the static (ground) position accuracy of the INS over a mission relatable period to isolate INS errors that are not caused by the dynamic (flight) environment. The static accuracy becomes a baseline for measuring the effects caused by the dynamic environment.

3.3.2.2. General

In static testing, the INS is evaluated while the aircraft remains on the ground. Dynamic testing is performed while airborne. Static testing allows the errors caused by the INS itself, whether cyclic, linear, exponential, etc. to be isolated from errors induced by maneuvering effects. The static accuracy becomes the baseline from which to gauge the effects of the dynamics of flight. One mission relation for static accuracy is to relate the requirement to perform quick reaction alerts with the INS navigating statically on the ground until launch time.

3.3.2.3. Instrumentation

A stop watch and data cards are required for this test, a voice recorder is optional.

3.3.2.4. Data Required

Record the actual surveyed alignment location latitude and longitude. At five minute intervals, starting at time zero, record the elapsed time and the displayed latitude and longitude. Completely describe any aircraft motion, including the time that it occurs and note any INS fault indications.

3.3.2.5. Procedure

Complete an alignment as outlined in the previous test technique, Initialization and Alignment. As the INS is placed in a navigation mode, start the stop watch and record the displayed latitude and longitude. Record the displayed latitude and longitude each five minutes. Completely describe any aircraft motion, along with the time of the occurrence. Record any INS fault indications. As a minimum, record data for the length of the maximum mission duration of the aircraft or two Schuler cycles, whichever is shorter.

3.3.2.6. Data Analysis and Presentation

Subtract the displayed latitude and longitude from the surveyed latitude and longitude. Convert the latitude and longitude difference into nm using equation (21). Plot the data as north-south and east-west error versus time. Annotate the plots with any significant events noted during the test, such as movement of the aircraft or system alerts. Analyze the trend of the plots for possible causes of the errors as outlined in the theory section. Relate the static accuracy to the requirement to remain on the ground, while the INS navigates statically, for long periods of time before a quick response alert launch. Check to see if a significant change in the error plot occurs at the time of aircraft motion or when system alerts occur. Relate the effects of aircraft motion to the requirement to perform maintenance on the aircraft after an alignment. Relate the static accuracy of the INS to the system alerts. Repeated alerts that imply degraded accuracy should be accompanied by that degradation or they are false alarms. Completely investigate any INS alerts following the test. Relate the occurrence of confirmed false alarms to the possibility of unnecessarily aborted sorties.

3.3.2.7. Data Cards

A sample data card is provided as card 39.

CARD NUMBER ___

STATIC POSITION ACCURACY

[AFTER PERFORMING THE INITIALIZATION AND ALIGNMENT TEST, SELECT A NAVIGATION MODE, START THE CLOCK AND RECORD DATA AT TIME 0 AND EACH 5 MINUTES AFTER. DESCRIBE ANY SIGNIFICANT MOVEMENT OR SYSTEM ALERTS AS NOTES AT THE APPROPRIATE TIME. CONTINUE THE TEST FOR _____ MINUTES.]

SURVEYED POSITION __________ __________

POINT NUMBER	ELAPSED TIME	DISPLAYED LATITUDE	DISPLAYED LONGITUDE	NOTES:

Card 39: Static Position Accuracy Data Card

3.3.3. Dynamic Non-maneuvering Position Accuracy

3.3.3.1. Purpose

The purpose of this test is to measure the dynamic, non-maneuvering position accuracy of the INS, to isolate the effects of non-maneuvering flight upon the INS, to isolate any degradation in accuracy due to an airborne vice ground alignment, and to qualitatively assess the utility of the INS as a navigation aid in the non-maneuvering environment.

3.3.3.2. General

Static testing provided a baseline of accuracy over time caused by errors inherent to the INS platform, accelerometers and gyroscopes. Dynamic, non-maneuvering position accuracy testing provides the next logical step in fully testing the INS. While airborne, the aircraft is flown in navigation profiles designed to demonstrate the effects of aircraft movement during flight while minimizing any maneuvering. The profiles are flown over maximum north-south and east-west distances to excite the effects of earth rate and coriolis. The flight duration should be equal to the maximum mission duration or two Schuler cycles, whichever is shorter. The optimum technique is to perform one flight on a predominately east-west profile and one on a predominately north-south profile. The maximum cruise range speeds should be used to allow the maximum latitude and longitude to be covered.

The flyover method explained earlier is used to provide the truth data. For this reason, a low altitude must be used. This restriction will reduce the mission duration for jet aircraft but is unavoidable without extensive instrumentation. During the test flight, the utility of the steering cues should be evaluated as an aid in finding the flyover points in a non-maneuvering environment. Both the INS displays/controls and the accuracy of the cues should be evaluated as an aid in acquiring the points visually in time to overfly the point without excessive maneuvering.

The test is repeated after performing an airborne alignment of the INS. A comparison of the data collected during the two tests then isolates the effects of the airborne alignment. The airborne alignment is discussed in the initialization and alignment test section.

3.3.3.3. Instrumentation

A stop watch and data cards are required for this test, a voice recorder is optional.

3.3.3.4. Data Required

After recording the initialization and alignment data, record the displayed latitude and longitude as a navigation mode is selected. Record the runway and location on the runway, elapsed time, and INS displayed latitude and longitude at takeoff. At each flyover point, record the elapsed time, surveyed point identification, altitude, offset bearing and range if required and INS displayed latitude and longitude. After landing and rolling out, record the runway and location on the runway, elapsed time and INS displayed latitude and longitude. After the taxi back to the hangar, record the surveyed parking location, elapsed time and INS displayed latitude and longitude. Throughout the flight, record as notes on the data cards, any maneuvers requiring over 1.5 g, 30° angle of bank, or 20° of pitch, any airspeed changes of over 50 KIAS (other than takeoff and landing) and any INS system alerts, along with the elapsed time of occurrence. Record qualitative comments concerning the utility of the INS displays/controls and navigation accuracy for navigating to and visually finding the surveyed flyover points in a non-maneuvering environment.

During the airborne alignment test, record the time at which the INS is cycled and the alignment is dumped, then record the time at which the airborne initialization is started. Record qualitative comments concerning the ease and complexity of the data entry. Note if the initialization process interferes significantly with other flight duties. Record the time at which the initialization is completed, and then the time when the flyover alignment is started. Record deviations from straight and level flight and constant airspeed throughout the alignment process as notes. Record the time at which the alignment is complete and then record all the airborne and landing data as outlined above.

3.3.3.5. Procedure

Prior to the test flight, plan a route that provides a flyover point each 5 to 15 minutes of flight time. If possible, plan one flight along a predominately north-south route, and one predominately east-west. Preflight planning of the flyover route is discussed in the navigation theory section. Plan and plot the route using normal low level visual navigation procedures as outlined in reference 59 "Trainee Guide for Visual Navigation". Choose an altitude that can be comfortably flown considering the maneuvering characteristics of the test aircraft, the experience of the pilot, the current weather conditions and the local terrain. Altitudes between 200 and 2,000 feet AGL are standard. VMC is required and care should be taken to choose a route clear of small airfields, areas of dense low level traffic, as well as areas of high bird activity. Generally, standard military VR routes are useful since the route planning has already been performed and scheduling/coordination is fairly simple. References 61 and 62 outline the VR structure and explain procedures for their use. Once a VR route is chosen, only surveyed points leading to and from the home airfield to the start and end point of the VR route need to be selected.

Perform an Initialization and Alignment test as previously outlined. When the alignment is complete, select a navigation mode, start the stopwatch and then record the displayed latitude and longitude. Following the published aircraft and airfield procedures, taxi to the takeoff area and at the time of takeoff, record the elapsed time, and displayed latitude and longitude. Note the location on the runway at the time the position is marked. Surveyed airfield diagrams (usually available at the tower) are later used to obtain the actual surveyed latitude and longitude.

Perform a normal airfield departure, navigating to the initial flyover point. Select an airspeed near the maximum range airspeed at the test altitude and set this airspeed as early as possible. Attempt to maintain this airspeed throughout as much of the flight as possible. Care must be taken to limit maneuvering. Keep g, pitch and bank to a minimum, recording the elapsed time and a complete description of all deviations. Generally, anything over 1.0 to 1.5g, 30° angle of bank, 20° of pitch or 50 KIAS of airspeed change should be noted.

Use visual reference points as well as the test INS and any other available navigation aids to find the first flyover point. The first point should be within 5 to 15 minutes of takeoff and each subsequent point should be at 5 to 15 minute intervals. Record the elapsed time, displayed latitude and longitude and altitude in feet MSL at each flyover point as well as the pilot's estimate of bearing and range to the point at the Closest Point of Approach (CPA) when the point is not directly overflown. Record any system alerts with the elapsed time as notes.

While navigating to the flyover points, evaluate the utility of the INS displays/controls, utility of the INS derived steering cues, as well as the integration of the navigation information within the aircraft as an aid in early visual location of the flyover points in the non-maneuvering environment. After visual location of the flyover point, evaluate the accuracy of the cues until overflight and afterwards the controls, displays and cues as an aid for navigation to the next point. The last flyover should occur 5 to 15 minutes before touchdown.

Following touchdown and rollout, record the elapsed time, runway location, latitude and longitude. Use the description of the runway location to again obtain the surveyed position from airfield charts. Taxi to a surveyed parking area and before shutdown, record the elapsed time and displayed latitude and longitude.

Repeat the test for the case of an airborne alignment. When approaching the first flyover point, cycle the INS, causing the alignment to dump, and start the stop watch. Perform an inflight initialization noting qualitative comments on the parameters listed in the previous section and the elapsed time at the completion of the initialization.

Begin the airborne alignment in conjunction with a flyover update at the first flyover point noting the elapsed time as the alignment begins. During the alignment, fly as straight and level as possible and minimize all speed changes. Note a complete description of any deviations of greater than 0.2 g, 15° angle of bank, 10° of pitch or 15 KIAS of speed change. Continue to fly the originally planned low level route and note the time when the alignment is complete. When complete, resume collection of the flyover data.

3.3.3.6. Data Analysis and Presentation

For points where the aircraft did not fly directly over the flyover point, use the pilot's estimate of bearing and range at the CPA to find the actual latitude and longitude. Convert the bearing to the point to true bearing and then resolve the vector into north-south and east-west components. Next, convert the components into differences in latitude and longitude. In the north-west hemisphere, add the difference in latitude when the point is to the south of the aircraft. Add the difference in longitude when the point is to the west of the aircraft. Use the equations below:

$$
\begin{gathered}
T_{bearing} = M_{bearing} - V \\
\Delta_{Lat} = \frac{(\Delta nm)}{\left(1\ \frac{nm}{min}\right)} \\
\Delta_{Long} = \frac{(\Delta nm)}{\left[\left(1\ \frac{nm}{min}\right)(\cos(LAT))\right]}
\end{gathered}
\tag{24}
$$

Subtract the INS displayed latitude and longitude from the surveyed flyover point latitude and longitude or the offset corrected latitude and longitude, as appropriate. Convert the latitude and longitude difference to nm using equation (21). Plot the data as latitude and longitude error versus elapsed time. Annotate the plots with any significant events noted during the test, such as system alerts or maneuvering above 1.5g, 30° angle of bank, 20° of pitch or airspeed changes of 50 KIAS. Analyze the trend of the plots for the possible causes of the errors as outlined in the navigation theory section. Relate the non-maneuvering accuracy of the INS to the requirement to perform non-maneuvering navigation during ferry missions and while ingressing from the base airfield to enemy lines. Subtract the recorded flyover point altitude above sea level (available from the same data base used to derive the surveyed latitude and longitude) from the recorded MSL aircraft altitude at flyover. 1/2 of this difference is the expected accuracy of the flyover derived truth data for a pilot experienced in the technique. Add an expected error of 25% of the offset range for an offset flyover.

Occasionally the pilot will overfly the wrong surveyed point. If a single point is grossly wrong while the others have plotted a more predictable drift rate, the individual point can be discounted. Occasionally the correct flyover point can be found by interpolating the appropriate navigation error from the curve of the error plot, adding it to the displayed latitude and longitude and then matching the position to the location of similar flyover points in the newly derived area. In this case, the new surveyed point can be used and the data will not be wasted.

If excessive maneuvers are recorded during the flight, check for significant changes in the error curves following the maneuver time. Relate excessive changes in the drift rate to the requirement to perform evasive maneuvers inbound to a target while still requiring accurate navigation information for the return to the home airfield. If system alerts are noted during the flight, check for significant changes in the error rate curve following the time the alert is noted. Thoroughly investigate any INS alerts after the flight. Alerts that imply degraded accuracy and do not result in a change on the error curve or cannot be associated with a system failure should be related to the possibility of unnecessarily aborted sorties (false alarms). Relate the utility of the INS displays/controls, steering cues and integration within the aircraft to the usefulness of the INS as an aid for navigating to waypoints, the target position and later returning to the home airfield.

3.3.3.7. Data Cards

A sample data card is provided as card 40.

CARD NUMBER ___ PRIORITY L/M/H

DYNAMIC NON-MANEUVERING POSITION ACCURACY

[AFTER PERFORMING THE INITIALIZATION AND ALIGNMENT TEST, SELECT A NAVIGATION MODE, START THE STOP WATCH AND RECORD THE LATITUDE AND LONGITUDE. RECORD DATA AT THE TAKEOFF ROLL POINT. AFTER TAKEOFF, SET ___KIAS, CLIMB TO ____ FEET MSL AND ASSUME LOW LEVEL NAVIGATION TO THE FIRST POINT. NAVIGATE TO EACH NUMBERED FLYOVER POINT AND RECORD DATA. RECORD AS NOTES, OFFSET FROM POINT, SYSTEM ALERTS AND MANEUVERS ABOVE 1.5G, 30° ANGLE OF BANK, 20° OF PITCH OR 50 KIAS OF AIRSPEED CHANGE WITH TIME AS REQUIRED. RECORD QUALITATIVE COMMENTS CONCERNING THE UTILITY FOR NON-MANEUVERING FLIGHT OF THE NAVIGATION DISPLAYS, STEERING CUES AND NAVIGATION ACCURACY. RECORD DATA AFTER ROLLOUT AND BEFORE SHUTDOWN.]

SURVEYED ALIGNMENT LOCATION __________ __________

DISPLAYED WHEN SELECTED __________ __________

DESCRIBE TAKEOFF POINT:

ELAPSED TIME AT TAKEOFF _____

DISPLAYED AT TAKEOFF __________ __________

NOTES:

Card 40: Dynamic Non-maneuvering Position Accuracy Data Cards

CARD NUMBER ___ PRIORITY L/M/H

DYNAMIC NON-MANEUVERING POSITION ACCURACY

TIME	POINT #	SURVEYED POSITION	DISPLAYED POSITION	ALTITUDE (FEET MSL)	NOTES:

Card 40: Dynamic Non-maneuvering Position Accuracy Data Cards (Continued)

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

DYNAMIC NON-MANEUVERING POSITION ACCURACY

DESCRIBE LOCATION OF ROLLOUT:

ELAPSED TIME AFTER ROLLOUT ______

DISPLAYED AFTER ROLLOUT __________ __________

SURVEYED SHUTDOWN LOCATION __________ __________

ELAPSED TIME AT SHUTDOWN _____

DISPLAYED AT SHUTDOWN __________ __________

QUALITATIVE COMMENTS CONCERNING UTILITY DURING NON-MANEUVERING FLIGHT OF NAVIGATION DISPLAYS/CONTROLS:

INS STEERING CUES:

NON-MANEUVERING ACCURACY:

Card 40: Dynamic Non-maneuvering Position Accuracy Data Cards (Continued)

3.3.4. Dynamic Maneuvering Position Accuracy

3.3.4.1. Purpose

The purpose of this test is to measure the dynamic maneuvering accuracy of the INS, to isolate the effects of various types of aircraft maneuvers and to qualitatively assess the utility of the INS as a navigation aid in the maneuvering environment.

3.3.4.2. General

Dynamic, non-maneuvering position accuracy testing provided a baseline of accuracy which included the effects of strictly non-maneuvering flight. Using this baseline plot, the aircraft will perform a series of maneuvers with flyover points taken after each maneuver. The exact flight profile will have little effect upon the accuracy compared to the effects of maneuvering. For this reason, a single flyover point can be repeatedly used. A significant departure from the dynamic baseline data plot will be due to aircraft maneuvering. In this way, the effects of mission relatable maneuvering upon INS accuracy will be isolated from other effects. Low acceleration roll, pitch (a loop maneuver will be used) and yaw maneuvers will be used to check for gimbal limits. Airspeed limitations will be checked while linearly accelerating from zero to the airspeed limit of the aircraft. Rolls, pitch, yaw, climbs, descents, and level turn maneuvers to the limits of the aircraft will be used to assess the effects of maneuvers in a single plane. Finally, rolling push-overs and pull-ups will be performed to the aircraft limits to check the effects of multi-axis maneuvers.

3.3.4.3. Instrumentation

A stop watch and data cards are required for this test, a voice recorder is optional.

3.3.4.4. Data Required

Following an initialization and alignment test, record the surveyed alignment location and the displayed latitude and longitude just as a navigation mode is selected. Just prior to takeoff, record the takeoff runway and position on the runway along with the elapsed time and displayed latitude and longitude. Following each maneuver, record the flyover elapsed time, displayed latitude and longitude and flyover altitude. Record applicable notes including offset bearing and range, as well as any INS system alerts including the time of occurrence. For the climb and descent data point, record the altitude and rate of climb at 5,000 feet increments. Following rollout, record the runway, location on the runway, elapsed time and displayed latitude and longitude. Just prior to shutdown, record the surveyed shutdown spot latitude and longitude, the elapsed time and displayed latitude and longitude. During the entire flight, record qualitative comments concerning the utility of the INS displays and navigation accuracy for navigating to and visually finding the surveyed flyover points in a maneuvering environment.

3.3.4.5. Procedure

During preflight planning, choose a flyover point in a working area (preferably a Restricted Area) that allows low and medium altitude maneuvering as well as supersonic flight at low and medium altitudes in the case of a supersonic test aircraft. A flyover point within 5 to 15 minutes of the home airfield is optimum; however, if a longer transit is required, choose flyover update points every 5 to 15 minutes between the home airfield and the maneuvering flyover point. Choose an initial airspeed that conserves fuel. A low altitude is best since flyover data will be required during the transit. Perform a flyover point as described in the dynamic non-maneuvering position accuracy section in the maneuvering area. Climb to a moderately low altitude in the case of an attack aircraft and a medium altitude in the case of a fighter aircraft and perform a maximum power acceleration to the limit airspeed or mach number of the aircraft. A shallow dive can be used to expedite the maneuver as long as it can be safely performed at the chosen altitude. When a dive is used, an initial altitude above the test altitude should be chosen. Generally, the rate of descent should never exceed 1/2 of the aircraft altitude for safety purposes.

Following the acceleration, decelerate to a good maneuvering speed while performing a 1.5 g or less turn, return to the flyover point and perform a flyover data point. Use a typical, low altitude for the flyover as described in the dynamic nonmaneuvering position accuracy test. Next climb to a medium low altitude and perform a constant 3 g, 360° turn. Use the best maneuvering airspeed, or the cornering airspeed, for the test. The cornering airspeed will be available from the aircraft operating manual. Return to the flyover location and repeat the flyover data point. Repeat at 5 g and then at the maximum aircraft level g. For the fighter aircraft test, perform the maximum g test at a medium altitude. Next, climb to a medium low altitude, set a good maneuvering airspeed and perform an aileron roll at 1/4 stick deflection. Return to the flyover point and perform a flyover data point. Repeat at 1/2 stick deflection and then at full stick deflection or at the aircraft roll limit, whichever is greater. Again at a medium low altitude provide a step rudder input at 1/4 and 1/2 rudder deflection and finally at either full rudder deflection or the aircraft rudder input limit. Perform a flyover update between each input.

Next, perform a maximum rate climb to a medium-high altitude, followed by a rapid descent to the flyover altitude. During the descent, ensure that no aircraft limits are exceeded. In general, when below 5,000 feet AGL, do not exceed a rate of descent greater than one half of the aircraft altitude. Perform a flyover update.

Finally, climb to a medium low altitude and perform a series of rolling push-overs and pull-ups, increasing the g to the aircraft limits. After reaching the aircraft limit, perform a final flyover data point. Return to the home airfield performing a flyover data point each 5 to 15 minutes of transit time as required. After the landing rollout, record the runway and runway position, elapsed time and displayed latitude and longitude. Before shut down, record the shut down spot surveyed latitude and longitude, the elapsed time and the displayed latitude and longitude. During the entire flight, watch for INS system discretes and record them as notes along with the time of occurrence. Thoroughly investigate all failure discretes after the flight. In addition, qualitatively evaluate the INS controls, steering cues, displays and accuracy as an aid for finding the flyover points in the maneuvering environment.

3.3.4.6. Data Analysis and Presentation

For data where the aircraft did not fly directly over the flyover point, use the recorded bearing and range at closest point of approach to find the actual latitude and longitude. Convert the bearing to the point to true bearing and then resolve the vector into north-south and east-west components. Next, convert the components into differences in latitude and longitude. In the north-west hemisphere, add the difference in latitude when the point is to the south of the aircraft. Add the difference in longitude when the point is to the west of the aircraft. Use the equations below:

$$T_{bearing} = M_{bearing} - V$$
$$\Delta_{Lat} = \frac{(\Delta nm)}{(\cos(LAT))} \tag{25}$$

Subtract the displayed latitude and longitude from the surveyed latitude and longitude or the offset corrected latitude and longitude as appropriate. Convert the latitude and longitude difference to nm using equation (25). Plot the data as latitude and longitude error versus elapsed time. Annotate the flyover points with the type of maneuvers performed just before each was taken. Check the plot for any significant change in the slope of the error plot and relate any changes to the effect these maneuvers have upon INS accuracy. Further relate the error to the loss of INS accuracy during mission relatable ACM for fighters and evasive maneuvering inbound to the target for attack aircraft.

If system alerts are noted during the flight, check for a significant change in the error rate curve following the time the alert is noted. Thoroughly investigate any INS alerts that imply degraded accuracy but do not result in a change in the error curve and do not result in malfunctions being found during the ground checks. The alerts should be related to the possibility of unnecessarily aborted sorties (false alarms). Relate the utility of the INS controls, displays, steering cues and integration within the aircraft to the utility of the INS as an aid for navigating to the target position and later returning to the home airfield, all while performing evasive maneuvers.

3.3.4.7. Data Cards

Sample data cards are provided as card 41.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

DYNAMIC MANEUVERING POSITION ACCURACY

[AFTER PERFORMING THE INITIALIZATION AND ALIGNMENT TEST, SELECT A NAVIGATION MODE. START THE STOP WATCH AND RECORD THE LATITUDE AND LONGITUDE. RECORD DATA AT THE TAKEOFF ROLL POINT. AFTER TAKEOFF, SET ___ KIAS, CLIMB TO _____ FEET MSL AND ASSUME NAVIGATION TO THE FLYOVER POINT, TAKING FLYOVER DATA ONCE THERE. PERFORM EACH MANEUVER AND BETWEEN EACH TAKE A FLYOVER DATA POINT. RECORD AS NOTES, OFFSET FROM POINT AND SYSTEM ALERTS. RECORD QUALITATIVE COMMENTS CONCERNING THE UTILITY FOR MANEUVERING FLIGHT OF NAVIGATION DISPLAYS/CONTROLS, STEERING CUES AND NAVIGATION ACCURACY. RECORD DATA AFTER ROLLOUT AND BEFORE SHUTDOWN.]

SURVEYED ALIGNMENT LOCATION __________ __________

DISPLAYED WHEN SELECTED __________ __________

DESCRIBE TAKEOFF POINT:

ELAPSED TIME AT TAKEOFF _____

DISPLAYED AT TAKEOFF __________ __________

NOTES:

Card 41: Dynamic Maneuvering Position Accuracy Data Cards

DYNAMIC MANEUVERING POSITION ACCURACY

AIRSPEED ___ KIAS

ALTITUDE _____ FEET MSL

FLYOVER POINT __________ __________

MANEUVER	ALT/AIR-SPEED (FT MSL/KIAS)	TIME	DISPLAYED	FLYOVER ALT (FT MSL)	NOTES:
INITIAL FLYOVER					
MAX LEVEL ACCEL					
LEVEL TURN 3G					
LEVEL TURN 5G					
LEVEL TURN _G					

Card 41: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

DYNAMIC MANEUVERING POSITION ACCURACY

MANEUVER	ALT/AIR-SPEED (FT MSL/KIAS)	TIME	DISPLAYED	FLYOVER ALT (FT MSL)	NOTES:
1/4 STICK ROLL					
1/2 STICK ROLL					
FULL STICK ROLL					
1/4 RUDDER					
1/2 RUDDER					
FULL RUDDER					

Card 41: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

DYNAMIC MANEUVERING POSITIONAL ACCURACY

MANEUVER (CLIMB OR DESCENT)	ALT/RATE OF CLIMB AT 5,000 FT INCREMENTS (FT MSL/FPM)	TIME	DISPLAYED	FLYOVER ALT (FT MSL)	NOTES:

Card 41: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

DYNAMIC MANEUVERING POSITION ACCURACY

MANEUVER	ALT/AIR-SPEED (FT MSL/KIAS)	TIME	DISPLAYED	FLYOVER ALT (FT MSL)	NOTES:
ROLLING PUSH-OVERS/ PULL-UPS					

DESCRIBE LOCATION OF ROLLOUT:

ELAPSED TIME AFTER ROLLOUT ______

DISPLAYED AFTER ROLLOUT __________ __________

SURVEYED SHUTDOWN LOCATION __________ __________

ELAPSED TIME AT SHUT DOWN _____

DISPLAYED AT SHUTDOWN __________ __________

QUALITATIVE COMMENTS CONCERNING UTILITY DURING MANEUVERING FLIGHT OF NAVIGATION DISPLAYS/CONTROLS:

INS STEERING CUES:

MANEUVERING ACCURACY:

Card 41: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

3.3.5. Dynamic Update Performance

3.3.5.1. Purpose

The purpose of this test is to evaluate the functionality and accuracy of the INS position update modes and to assess their utility in a tactical environment.

3.3.5.2. General

As explained in the navigation theory section, the long term accuracy of the INS is usually enhanced through periodic manual updates. The update modes allow resetting the displayed position to a given reference point or to a known bearing and range from a given reference point. The sample INS used in this book can be updated using a visual flyover (or waypoint) mode, radar, TACAN and OMEGA modes. The waypoint update is performed similar to the flyover point method. The latitude and longitude of the flyover point are loaded into the INS computer as a waypoint. At the instant the point is visually overflown an update is made and the INS latitude and longitude are changed to the waypoint latitude and longitude. During a radar update, the position of the radar target is loaded as a waypoint. The radar target is designated on the radar display and the bearing and range to the target are automatically converted to an offset of latitude and longitude from the known radar target position. This radar offset latitude and longitude becomes the current position at the time the update is performed. In a TACAN update, the TACAN ground station position is loaded as a waypoint and the TACAN radial and DME are used in a fashion similar to the radar bearing and range to provide a latitude and longitude offset at the time the update is performed. In the OMEGA update, the OMEGA calculated latitude and longitude are used directly to update the INS current position.

As with the flyover method, the waypoint update accuracy is approximately equal to 1/2 of the height above the update point, assuming an accurately surveyed update point position is known. The radar and TACAN update accuracies depend upon the surveyed position accuracy of the radar target and TACAN ground station, the bearing and range accuracy of the radar and accuracy of the TACAN. A method for determining the bearing and range accuracy of an air-to-ground radar was described in the radar theory section and as described in the navigation theory section, the expected TACAN accuracy is approximately 3.5° and 0.1 to 3 nm. The OMEGA update accuracy depends upon the position fixing accuracy of the OMEGA itself. As was explained earlier, the only parameter updated is the position, the rate of the drift will not be affected significantly by the update.

3.3.5.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

3.3.5.4. Data Required

Prior to the first update, record the initial flyover data point elapsed time, displayed latitude and longitude and the flyover altitude. After performing each update, record the flyover elapsed time, displayed latitude and longitude and altitude. For each flyover data point and for the waypoint update, record the offset bearing and range, if applicable, as notes. During the entire flight, record qualitative comments concerning the utility of the INS update modes including the ease of the updates, utility of the controls used for each update, the integration of the INS with the TACAN, radar and OMEGA used in the updates as well as the update accuracy.

3.3.5.5. Procedure

Prior to the test flight, select a flyover point in a working area (preferably a Restricted Area) that allows maneuvering for repeated flyover passes. Select a surveyed radar target close enough to the flyover point to be within the detection volume of the radar while overhead the flyover point. Finally, find the latitude, longitude, channel and identifier code for the TACAN station closest to the flyover point. Choose an airspeed that conserves fuel. Since a number of flyover points will be performed in rapid succession, the entire test should be flown from approximately 200 to 2,000 feet AGL. The lowest altitude that can be flown considering the maneuvering characteristics of the aircraft, the qualifications of the pilot and the local terrain should be chosen. The TACAN may be switched through channels as required to navigate to the flyover point. After the initial flyover point is performed, limit all maneuvers to 1.5g or less, 30° angle of bank, 20° of pitch and less than 50 KIAS of airspeed change to isolate the effects of aircraft maneuvers from the effects of the update accuracy. In addition, perform the flyover data points as quickly after the updates as possible to reduce the amount of drift in the INS between the update and the flyover point.

Perform a waypoint update using the published procedures for the INS and the same flyover point used for the flyover data. Record the altitude above the update point. If necessary, repeat the waypoint update until little or no offset is noted at the update point. Following the final waypoint update, perform a flyover data point, recording the displayed latitude and longitude and the flyover altitude and then turn outbound towards the chosen radar target. Using the published aircraft procedure, perform a radar update of the INS and then repeat the flyover data point. Next, dial in the TACAN station chosen during preflight (if it is not already being used) and after the TACAN is properly tracking the ground station, perform a TACAN update of the INS in accordance with the published procedure. Perform a third flyover data point. Finally, perform an OMEGA update in accordance with the published procedures and then perform the last flyover data point. Throughout the flight, record INS alerts along with the time of occurrence, as notes. Thoroughly investigate all failure indications after the flight. In addition, qualitatively assess the utility of the INS update modes including the ease of the updates, the utility of the controls used for each update, the integration of the INS with the TACAN, radar and OMEGA used in the updates, as well as the update accuracy.

3.3.5.6. Data Analysis and Presentation

For flyover point data where the aircraft did not fly directly over the flyover point, use the recorded bearing and range at CPA to find the actual latitude and longitude. Convert the bearing to the point to true bearing and then resolve the vector into north-south and east-west components. Next, convert the components into differences in latitude and longitude. In the north-west hemisphere, add the difference in latitude when the point is to the south of the aircraft. Add the difference in longitude when the point is to the west of the aircraft. Use the equations below:

$$T_{bearing} = M_{bearing} - V$$
$$\Delta_{Lat} = \frac{(\Delta nm)}{\left(1\ \frac{nm}{min}\right)} \qquad (26)$$
$$\Delta_{Long} = \frac{(\Delta nm)}{\left[\left(1\ \frac{nm}{min}\right)(\cos(LAT))\right]}$$

Subtract the displayed latitude and longitude from the surveyed latitude and longitude or the offset corrected latitude and longitude as appropriate. Convert the latitude and longitude difference to nm using equation (21). Since the flyover points are taken immediately after the updates, the errors can be used to closely represent errors in the updates. Compare the noted errors to the expected accuracies of the update sources. The expected accuracy of the waypoint update is 1/2 of the height above the update point. The radar accuracy is as measured during the bearing and range accuracy test. The TACAN accuracy is around 3.5° and 0.1 to 3 nm as described in the navigation theory section. The OMEGA accuracy is approximately 1 nm in the daytime and 2 nm at night. Relate the accuracy of the update (both expected and unexpected) to the navigational accuracy required to safely ingress to the target area for an attack aircraft and for the necessity to find the home field in IMC conditions after a mission for the fighter aircraft.

Thoroughly investigate any INS alerts that imply degraded accuracy. Alerts that do not result in malfunctions being found during the ground check should be related to the possibility of unnecessarily aborted sorties (false alarms). Relate the ease with which each update is performed to the requirement to perform the updates in a highly stressful combat environment and while simultaneously performing other functions such as avoiding enemy defenses. Relate the integration of the INS, radar, TACAN and OMEGA controls within the same context. Relate the utility of the displays used during the INS update to the effect that performing the update has upon the scan of other vital tactical information such as visually scanning for surface to air missiles.

3.3.5.7. Data Cards

Sample data cards are provided as card 42.

CARD NUMBER ___ TIME _____ PRIORITY L/M/H

DYNAMIC UPDATE PERFORMANCE

[INSURE TACAN AND OMEGA ARE TURNED ON AND INITIALIZING. SET ___KIAS, CLIMB TO ___MSL AND ASSUME NAVIGATION TO FLYOVER. RESTRICT MANEUVERING TO 1.5 G, 30° ANGLE OF BANK, 20° OF PITCH AND 50 KIAS OF AIRSPEED CHANGE. PERFORM EACH UPDATE AND BETWEEN EACH TAKE A FLYOVER DATA POINT. REPEAT THE WAYPOINT UPDATE UNTIL OPTIMIZED. RECORD AS NOTES, OFFSET FROM THE POINT, AS WELL AS SYSTEM ALERTS. RECORD QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE UPDATE MODES INCLUDING THE EASE OF UPDATE, UTILITY OF THE CONTROLS USED FOR EACH UPDATE, INTEGRATION OF THE INS WITH THE TACAN, OMEGA AND RADAR SYSTEMS USED IN THE UPDATES, AS WELL AS THE UPDATE ACCURACY.]

FLYOVER POINT __________ __________

DESCRIBE POINT:

RADAR TARGET __________ __________

DESCRIBE TARGET:

UPDATE TACAN POSITION __________ __________

TACAN CHANNEL/IDENTIFIER ___/____

Card 42: Dynamic Update Performance Data Cards

DYNAMIC UPDATE PERFORMANCE

WAYPOINT UPDATE ALTITUDE (FT MSL)/OFFSET _____/_____

UPDATE	DISPLAYED	FLYOVER ALT (FT MSL)	NOTES:
WAYPOINT			
RADAR			
TACAN			
OMEGA			

NOTES:

Card 42: Dynamic Update Performance Data Cards (Continued)

DYNAMIC UPDATE PERFORMANCE

QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE INS UPDATE MODES INCLUDING THE EASE OF THE UPDATES:

UTILITY OF THE UPDATE CONTROLS/DISPLAYS:

INTEGRATION OF THE INS WITH THE RADAR/TACAN/OMEGA SYSTEMS:

NOTES:

Card 42: Dynamic Update Performance Data Cards (Continued)

3.3.6. Mission Utility and Integration

3.3.6.1. Purpose

The purpose of this test is to qualitatively assess the utility of the INS and its integration with the other aircraft systems.

3.3.6.2. General

In most cases, the INS is not a stand alone system. Many modern avionics systems require navigation inputs. Radar and Forward Looking Infrared Radar (FLIR) displays and antennas are often geographically stabilized using INS inputs. The INS can use sensor and other navigation system inputs for position updates. Navigation information is often displayed on radar and FLIR displays, tactical displays and HUDs. A typical system will use radar input to the navigation system as initial steering to the target (the navigation system also is stabilizing the radar scan center to maintain detection of the target). The navigation input is then used to steer the FLIR onto the target for a FLIR handoff. The navigation cues are provided on the HUD, often including an INS stabilized target designator box, to aid in visually finding the target. If detection is lost, such as during the terminal phase of a DBS radar attack, the INS provides final attack cues. Finally, during the weapons release, the INS provides inputs to the weapons computer to calculate the proper release point, again providing cues to the pilot.

In most cases, the INS requires the widest integration within the complete aircraft of any system and as such is the most challenging to test for integration. Since the output of the INS (latitude and longitude) is rarely used directly by the pilot, the issue of integration and accuracy nearly completely define the utility of the INS.

The utility and integration of the INS can only be evaluated during mission relatable tasks. For an attack aircraft, the evaluation must be performed during mission relatable ingresses to the target area, detection of the target, handoff between the sensors as would be expected in a tactically significant attack (for example a handoff from a long range radar detection to a FLIR attack), selection of a weapon and attack mode and finally a safe egress from the target area. For a fighter, the evaluation requires navigating to and from a Combat Air Patrol (CAP) station, steering cues to a radar designated target, handoff to an air-to-air FLIR or other electro-optic sensor for VID as well as navigation inputs to digital data links and tactical displays. The critical requirement is to select a scenario that reflects the most likely use of the aircraft and to use this scenario during the evaluation. For the purpose of this sample test procedure, the test aircraft will be an attack aircraft with a weapons computer, HUD, radar and FLIR as well as the TACAN and OMEGA systems used to demonstrate the previous tests.

3.3.6.3. Instrumentation

Data cards are required for this test. A voice recorder is highly recommended.

3.3.6.4. Data Required

Record qualitative comments concerning the integration of the INS with the aircraft weapons computer, FLIR, HUD, radar, TACAN and OMEGA. Include comments concerning the INS inputs to these systems as well as the radar, TACAN and OMEGA inputs to the INS for INS updates. Evaluate the effects of INS accuracy upon other systems, for instance the drift rate of radar and FLIR geographically stabilized cursors, once a target is selected, and the resulting workload as the cursors are repeatedly updated. Evaluate the effects of navigation functions, such as INS update procedures, upon operator workload in a mission relatable environment. Assess the utility of the INS derived information displayed upon the radar, FLIR, HUD and INS unique displays including the effects of INS accuracy, while performing radar to FLIR or HUD handoffs and mission relatable ingresses, attacks and egresses.

3.3.6.5. Procedure

Select a mission relatable target in the test area that allows for a 35 to 40 nm ingress to the target location. Select several waypoints inbound to the target. While navigating from the home airfield to the initial waypoint, qualitatively assess the utility of the INS accuracy and steering cues for long range, IMC navigation. Choose an altitude and airspeed that conserves fuel. Descend to a low ingress altitude and set an airspeed near the sea level limit of the test aircraft. Head inbound to the target and select a radar mapping mode with at least a 40 nm scale and a wide scan pattern useful for radar mapping. Follow the INS and radar cues inbound to the target, passing over the waypoints along the route. Select DBS radar modes inbound to the target and when inside of 10 nm perform a handoff of the target from the radar to the FLIR. Continue inbound to the target, performing a mission relatable unguided ordnance attack. Following the attack, turn outbound from the target and navigate to the initial point on the reverse route using the radar and INS cues. Repeat with different weapons deliveries as time allows. Use a voice recorder or write down comments after each run. Care should be taken not to become distracted with recording data to allow the best overall qualitative evaluation.

3.3.6.6. Data Analysis and Presentation

Relate the qualitative deficiencies noted to their effects upon the performance of normal IFR navigation, ingresses and attacks. Note any limitations upon tactics imposed by the INS accuracy, utility or integration. For instance, the navigation cues used to find the waypoints may require so much operator attention and interpretation that they destroy the scan of the radar display while searching for the target. As another example, the INS drift may be so high that the stored position of the target may drift radically between the last radar or FLIR update and the weapons release, causing a miss of the target. It is critical that the INS utility and integration should not be driving tactics. Use the applicable results from the previous tests to support the qualitative results.

3.3.6.7. Data Cards

A sample data card is presented as card 43.

CARD NUMBER ___ TIME___ PRIORITY L/M/H

INS MISSION UTILITY AND INTEGRATION

[AFTER TAKEOFF, CLIMB TO _____ FEET MSL AND SET ___ KIAS. PERFORM INS NAVIGATION TO THE INITIAL POINT, ASSESSING THE UTILITY OF THE INS'S ACCURACY AND DISPLAYS FOR IMC NAVIGATION. DESCEND TO ___ FEET AGL AND SET ___ KIAS AT THE INITIAL WAYPOINT. SET A 40 NM RADAR SCALE AND __° SCAN ANGLE LIMIT. SEARCH FOR THE TARGET ON THE RADAR WHILE NAVIGATING TO THE WAYPOINTS. AT 10 NM, PERFORM A FLIR HANDOFF. PERFORM A__________ ATTACK. AFTER RELEASE, REVERSE THE INGRESS TRACK. REPEAT USING A __________, __________ AND __________ ATTACK AS FUEL ALLOWS.]

TARGET POSITION __________ __________

INITIAL WAYPOINT 1 POSITION __________ __________

WAYPOINT 2 POSITION __________ __________

WAYPOINT 3 POSITION __________ __________

NOTES:

Card 43: INS Mission Utility and Integration Data Card

3.3.7. Introduction to Advanced Inertial Navigation System Test Techniques

As mentioned in Chapter 1, only the most rudimentary form of the inertial navigation system test techniques are presented in this book. Chapter 1 details the reasons for this format; however, in many applications, more rigor, accuracy and documentation of results are required. Table IV outlines additional instrumentation and assets which are typically applied in these more advanced tests. The purpose of this table is merely to emphasize the existence of these advanced techniques. Further, this list is not exhaustive. Many innovative uses of assets and instrumentation exist. It is hoped that the examples provided leave the reader with a taste of how the test can be made more rigorous through the judicious use of instrumentation. In application, the user must refer to the more advanced documents referenced in Chapter 1 or solicit help from more experienced testers.

Table IV: Additional Assets or Instrumentation for use in Advanced Inertial Navigation System Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Preflight and Built-in-Tests.	Digital Recorder.	Typically records data from data bus on which navigation system under test passes the BIT results. Allows precise documentation of test results. Usually used in conjunction with fault insertion tests.
	Video recording of display.	Provides automatic recording of what the operator sees as a fault status is displayed.
Controls and Displays.	Video recording of display.	Allows automatic documentation of display problems as well as post-flight analysis and evaluation.
	Cockpit mock-ups, reconfigurable cockpits and virtual cockpits.	Typically used for in-depth ground tests of human factors and in iterative cockpit design.
	Digital recording of operator actions.	Can be used as a means of precisely recording operator selections to document noted problems and as a means of performing operator task analysis.
Initialization and Alignment.	Digital recording of navigation data bus to include all Inertial Navigation System (INS) outputs, alignment parameters and operator actions and inputs. Precisely surveyed alignment location and boresighted aircraft heading and orientation.	Entire alignment process is captured allowing isolation of poor alignment performance. Initialization process is recorded and correlated to operator selections. Final alignment results are compared to known alignment location and aircraft orientation.

Table IV: Additional Assets or Instrumentation for use in Advanced Inertial Navigation System Tests (Continued)

Test	Additional Asset or Instrumentation	Purpose/Benefit
Static Position Accuracy.	Digital recording of INS derived position and rates. Video recording of display. Precisely surveyed alignment location.	Digital position and rates are compared to the known static values. Display output to the operator is compared to the direct INS output.
Dynamic Non-maneuvering Position Accuracy.	Digital recording of aircraft dynamics, precise, time stamped space positioning data, INS derived position and rates, and operator actions. Video recording of the display.	The profile is flown without the necessity of surveyed point flyovers. Space positioning data and aircraft dynamics are continuously recorded and later compared to INS derived values. If derived from a range, the profile is often constrained geographically. Recently, Global Positioning System (GPS) data can be used with sufficient accuracy to avoid constricting the profile. Recorded aircraft dynamics are also examined to correlate maneuvering excursions with changes in INS drift rates. The display video is compared to the INS bus data to check for inconsistencies caused by the manipulation of the INS data and then its display.
Dynamic Maneuvering Position Accuracy.	Digital recording of aircraft dynamics, precise, time stamped space positioning data, INS derived position and rates, and operator actions. Video recording of the display.	Typically, precise space positioning data is derived from an instrumented range. Aircraft dynamics can be derived from either on or off the aircraft. The INS derived rates and position are compared directly with the time correlated data as the maneuvers are performed. The display video is used as above.
Dynamic Update Performance.	Digital recording of aircraft dynamics, precise, time stamped space positioning data, INS derived position and rates, and operator actions. Video recording of the display.	The data is used similarly to the Dynamic Non-maneuvering Position Accuracy test with the comparisons of position and rates performed after each update.

 Table IV: Additional Assets or Instrumentation for use in Advanced Inertial Navigation System Tests (Continued)

Test	Additional Asset or Instrumentation	Purpose/Benefit
Mission Utility and Integration.	Digital recording of aircraft dynamics, precise, time stamped space positioning data, INS derived position and rates, and operator actions. Video recording of the display. Digital recording of all navigation data passed to other aircraft systems.	This test requires the largest amount of data to completely document the results. It is during this test that most of the unexpected problems are found. In anticipation of having to document these deficiencies, maximum instrumentation and range support are sometimes brought to bear in case unforseen data are required in post-flight analysis.

3.4. OMEGA NAVIGATION SYSTEM TEST TECHNIQUES

3.4.1. Initialization

3.4.1.1. Purpose

The purpose of this test is to determine the amount of time that the OMEGA requires from the time it is turned on until it begins providing a position (initialized) and to assess the effects that this time has upon the launch preparation time.

3.4.1.2. General

After the OMEGA is turned on and the initial position provided by the operator, the OMEGA computer then searches for the signals from the OMEGA ground stations. In modern, airborne OMEGAs, the ground stations used at the initial position are selected from an internal table and are based upon the geometry to the stations. The stations are selected to limit the effects of GDOP by choosing pairs that provide hyperbolic lines that cross at as close to 90° as possible. In addition, the effects of the differences in day and night propagation, the day/night transition line, near station modal interference and PCA are usually considered in station selection. Following station selection, the OMEGA must analyze the phase relationship of the signals and integrate to a solution. The initial fix can take from 1 to 5 minutes depending upon the characteristics of the OMEGA being tested and the propagation characteristics of the day.

In addition to selection of stations, the initial fix is used to determine the initial lane location. The lanes are ambiguous every 8 nm in the worst case, and station selection changes over even longer distances, and so taxi distances before takeoff have little or no effect upon the OMEGA initialization. For this reason, the factor limiting the allowable integration time is the time from OMEGA turn on to takeoff, where the first OMEGA position display is required. The time to turn on the OMEGA, input the initial position, and for the OMEGA to select the ground stations and to integrate to a solution should be less than the alert launch requirement of the aircraft. This test should be repeated over as many days as possible to allow for a wide variance of propagation characteristics. Since the entire procedure can be quite time consuming, some status indication is required to indicate to the operator that the process is proceeding normally and as an indicator of the approximate time left to completion. Finally, the operator must be alerted to the fact that the OMEGA has integrated to an initial solution and is ready for flight. Generally an operator alert is provided.

3.4.1.3. Data Required

Record the time from when the initial position is input to the OMEGA to the time that the initialization complete alert is provided. Record qualitative comments concerning the utility of the initialization complete alert as an indicator that the OMEGA is ready for flight. Record qualitative comments concerning the effects that the time required for initialization of the OMEGA will have upon mission relatable quick reaction alert launches. Record as notes a description of the weather conditions.

3.4.1.4. Instrumentation

A stop watch and data cards are required for this test. A voice tape recorder is optional.

3.4.1.5. Procedure

Perform a preflight/BIT, starting the stop watch immediately after entering the initial latitude and longitude. Allow the OMEGA to automatically select the internally derived ground stations. Monitor the status indications as the OMEGA integrates to an initial fix. Note the elapsed time when an alert is posted, indicating that the OMEGA has integrated to an initial fix and that the system is ready for flight.

3.4.1.6. Data Analysis and Presentation

Add the time required to turn on and input the initial latitude and longitude to the time required for the OMEGA to integrate to an initial position and post an alert. Relate the time required to the time available to make an alert launch and the possibility of launching without OMEGA derived position information. Relate the clarity and accuracy of the initialization status indications to the possibility of prematurely initiating troubleshooting procedures while waiting for an initialization complete alert. Relate the clarity and location of the initialization complete indication to the possibility of missing the alert and delaying the launch.

Severe weather may interfere with the ground station signals and may thus prolong the initialization process. If the initialization time is excessive and weather problems are suspected, repeat the test in clear weather conditions. Relate weather effects to the necessity to launch with adverse weather in the vicinity.

3.4.1.7. Data Cards

A sample data card is provided as card 44.

CARD NUMBER ___

OMEGA INITIALIZATION

[START THE STOP WATCH IMMEDIATELY AFTER THE INPUT OF THE INITIAL LATITUDE AND LONGITUDE. RECORD THE TIME WHEN THE INITIALIZATION IS COMPLETE. RECORD QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE INITIALIZATION STATUS AND INITIALIZATION COMPLETE INDICATIONS.]

INITIAL POSITION __________ __________

TIME THE INITIALIZATION IS COMPLETE _____

QUALITATIVE COMMENTS:

Card 44: OMEGA Initialization Data Card

3.4.2. Dynamic Position Accuracy

3.4.2.1. Purpose

The purpose of this test is to determine the position fixing accuracy of the OMEGA system within the extremes of the expected groundsite geometries.

3.4.2.2. General

As described in the navigation theory section, diurnal effects, ground conductivity effects (with the exception of attenuation over the polar ice caps) and the earth's shape effects are fairly predictable and are accounted for within the OMEGA computer. Near station modal interference, long range, directional ambiguity and polar cap attenuation effects are compensated for by automatically deselecting stations inside 200 to 500 nm, beyond approximately 8,500 nm and with propagation paths over the polar ice caps. The exact ranges vary from system to system and are determined and set by the designer. The exact values can be determined from the manufacturer documentation as can plots of the areas where stations are deselected due to polar cap attenuation. SIDs and PCAs are unpredictable for the most part, cannot be accounted for, and therefore cannot be tested for within the time and cost constraints of this test since a complete investigation would require testing over great periods of time and atmospheric conditions.

The performance degradation of the OMEGA due to three of the above effects will be specifically isolated in this procedure. The pilot is typically given an indication of the OMEGA stations in use on the OMEGA navigation display. The performance of the OMEGA in selecting and deselecting these stations due to near station modal interference, long range, directional ambiguity and PCA can be measured by noting the stations in use as the aircraft transits these areas. These effects can be isolated by assuming that the errors will not be significant as long as the selections are performed correctly. The measured accuracy can then be assumed to be influenced by some combination of the remaining effects discussed in the OMEGA theory section. The exact contributions will generally be indeterminate by this technique. The aggregate effects of errors in the internal compensation routines of the OMEGA computer and the uncompensable errors can; however, be assumed to be satisfactory as long as the total error is within mission relatable tolerances. Further testing, requiring more sophisticated data gathering techniques and instrumentation, will be required if the error is beyond these limits.

With the exception of the time dependent variations of the PCA and SIDs, the OMEGA errors are generally not dependent upon time as were the INS errors. The effects are generally dependent upon station geometry. The testing emphasis is then shifted from time dependency to placing the system in as many station geometry situations as possible. Maximum range airspeeds are used to maximize the number of different geometric relationships possible in a single flight. In addition, the data is generally plotted in the form of a north-south/east-west error scatter plot vice an error versus elapsed time plot. [Ref. 38:p. 4.22a].

3.4.2.3. Instrumentation

Data cards and an optional voice recorder are required for this test.

3.4.2.4. Data Required

Following an OMEGA initialization, record the stations in use and the displayed latitude and longitude. Immediately prior to takeoff, record the runway, runway location, stations in use, and displayed latitude and longitude. At each flyover point, record the selected stations, surveyed point identification, altitude, and OMEGA displayed latitude and longitude. After landing and rollout, record the runway, runway location, stations in use, and the displayed latitude and longitude. Throughout the flight, record any OMEGA alerts and note the latitude and longitude when stations are deselected for near station modal interference, long range, directional ambiguity and PCA. Record qualitative comments concerning the utility of the OMEGA displays/controls and navigation accuracy for navigating to and visually finding the surveyed flyover points. Record as notes a description of the weather conditions.

3.4.2.5. Procedure

Prior to the flight, plan a route that provides a flyover point each 5 to 15 minutes of flight time. Preflight planning of the flyover route is discussed in the navigation theory section. Plan and plot the route using normal low level visual navigation procedures as outlined in reference 59 "Trainee Guide for Visual Navigation". Choose an altitude that can be comfortably flown considering the maneuvering characteristics of the test aircraft, the experience of the pilot, the current weather conditions and the local terrain. Altitudes between 200 and 2,000 feet AGL are standard. Visual Meteorological Conditions (VMC) are required and care should be taken to choose a route clear of small airfields, areas of dense low level traffic, as well as areas of high bird activity. Generally, standard military VR routes are useful since the route planning has already been performed and scheduling/coordination is fairly simple. References 61 and 62 outline the VR structure and explain procedures for their use. Once a VR route is chosen, only surveyed points leading to and from the home airfield to the start and end point of the VR route need to be selected.

If possible, a route should be chosen to exercise the OMEGA ground station select logic for near station modal interference, long range, directional ambiguity and PCA. The manufacturer's handbook on the OMEGA's operation will provide charts of the points at which the stations should deselect and reselect due to these three effects. In many cases, flight time, cost and home airfield location will not allow this to be performed; however, an attempt should be made, if possible. For most tests within the continental United States, the North Dakota station will be used to check near station modal interference deselection, the Norway station will be best for checking PCA deselection and the Liberia station will be best for checking long range, directional ambiguity deselection.

Perform an OMEGA initialization test. When the initialization is complete, record the stations in use and then the displayed latitude and longitude. Following normal aircraft and airfield procedures, taxi to the takeoff area and at the time of takeoff, record the stations in use and the displayed latitude and longitude. Note the aircraft location on the runway at the time the position is marked. This position can later be used to obtain the actual surveyed latitude and longitude.

Perform a normal airfield departure, navigating to the initial flyover point. Select an airspeed near the maximum range airspeed at the test altitude and set this airspeed as early as possible. Attempt to maintain this airspeed throughout as much of the flight as possible. Use visual reference points as well as the test OMEGA and any other available navigation aids to find the first flyover point. The first point should be within 5 to 15 minutes of takeoff and each subsequent point should be at 5 to 15 minute intervals. Record the stations in use and the displayed latitude and longitude at each flyover point as well as the bearing and range to the point when the point is not directly overflown. Record any system alerts with the elapsed time as notes.

While navigating to the flyover points, evaluate the utility of the OMEGA displays/controls, utility of the OMEGA derived steering cues, as well as the integration of the navigation information with the aircraft as an aid in early visual location of the flyover points. After visual location, evaluate the accuracy of the cues until overflight and afterwards the controls, displays and cues as an aid for immediate navigation to the next point. The last flyover should occur 5 to 15 minutes before touchdown. Following touchdown and rollout, record the stations in use, runway location, latitude and longitude. Use the description of the runway location to again obtain the surveyed location from airfield charts. Taxi to a surveyed parking area and before shutdown, record the stations in use and displayed latitude and longitude. Record the displayed latitude and longitude when the OMEGA deselects a station for near station modal interference, long range, directional ambiguity or PCA.

3.4.2.6. Data Analysis and Presentation

For data where the aircraft did not fly directly over the flyover point, use the recorded bearing and range at CPA to find the actual latitude and longitude. Convert the bearing to the point to true bearing and then resolve the vector into north-south and east-west components. Next, convert the components into differences in latitude and longitude. In the north-west hemisphere, add the difference in latitude when the point is to the south of the aircraft. Add the difference in longitude when the point is to the west of the aircraft. Use the equations below:

$$T_{bearing} = M_{bearing} - V$$

$$\Delta_{Lat} = \frac{(\Delta nm)}{\left(1\ \frac{nm}{min}\right)} \tag{27}$$

$$\Delta_{Long} = \frac{(\Delta nm)}{\left[\left(1\ \frac{nm}{min}\right)(\cos(LAT))\right]}$$

Subtract the displayed latitude and longitude from the surveyed latitude and longitude or the offset corrected latitude and longitude as appropriate. Convert the latitude and longitude difference to nm using equation (21). Plot the data as a scatter plot of the east-west errors on the x axis and the north-south errors on the y axis. Since the errors are not time dependent, the data from a number of flights may be combined as long as the basic system set up does not change. The scatter plot may be statistically analyzed to determine the parameters quoted within the specific system specification for the OMEGA under test. Generally, a calculation of the mean error, standard deviation and Circular Error Probable (CEP) will be required. Reference 45 provides a good discussion of the techniques for determining these parameters. Relate the accuracy of the OMEGA to the requirement to perform non-maneuvering navigation during ferry missions and while ingressing from the base airfield to enemy lines and to the requirement for updating the aircraft INS to correct for drift.

Occasionally the pilot will overfly the wrong surveyed point. If a single point is grossly wrong while the others have a more predictable error, the individual point can be discounted. Often, the correct flyover point can be found by inferring the appropriate navigation error from the error of adjacent data points and the presence of other targets on the TPC used for navigation. In this case, the new surveyed point can be used and the data will not be wasted.

If system alerts are noted during the flight, check for significant change in the error data following the time the alert is noted. Thoroughly investigate any OMEGA alerts that imply degraded accuracy and do not result in a change on the error plot or a malfunction being found during ground checks. Alerts that do not result in degraded accuracy or problems being found during the ground checks should be related to the possibility of unnecessarily aborted sorties (false alarms).

Relate the utility of the OMEGA displays, steering cues and integration within the aircraft to the utility of the OMEGA as an aid for navigating to the target position and later returning to the home airfield and as an aid in updating the INS after it drifts. Compare the positions where the OMEGA deselects and reselects ground stations for near station modal interference, long range, directional ambiguity and PCA to the manufacturer's charts of the designed selection and deselection points. Relate any discrepancies of greater than 50 nm to the possibility of increased errors due to the applicable effect. Relate any change in the error during the periods where the OMEGA stations are incorrectly selected or deselected to the reduced effectiveness of the OMEGA as an aid for navigation and updating the INS.

Severe weather may interfere with the ground station signals and may thus degrade the dynamic accuracy. If the accuracy is poor and weather problems are suspected, repeat the test in clear weather conditions to confirm the problem source. Relate weather effects to the necessity to fly in the vicinity of adverse weather.

3.4.2.7. Data Cards

Sample data cards are provided as card 45.

CARD NUMBER ___

DYNAMIC POSITION ACCURACY

[AFTER PERFORMING AN OMEGA INITIALIZATION TEST, NOTE THE SELECTED STATIONS AND RECORD THE LATITUDE AND LONGITUDE. RECORD DATA AT THE TAKEOFF ROLL POINT. AFTER TAKEOFF, SET ___KIAS, CLIMB TO ____ FEET MSL AND ASSUME LOW LEVEL NAVIGATION TO THE FIRST POINT. NAVIGATE TO EACH FLYOVER POINT AND RECORD THE DATA. RECORD THE OFFSET FROM THE POINT, SYSTEM ALERTS AND DESELECTION POINTS AS REQUIRED. RECORD QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE NAVIGATION DISPLAYS, STEERING CUES AND NAVIGATION ACCURACY. RECORD DATA AFTER ROLLOUT AND BEFORE SHUTDOWN.]

SURVEYED ALIGNMENT LOCATION __________ __________

STATIONS IN USE ____

DISPLAYED WHEN SELECTED _________ __________

EXPECTED POINTS OF DESELECTION:

N. DAKOTA __________ __________

LIBERIA __________ __________

NORWAY __________ __________

NOTES:

Card 45: Dynamic Position Accuracy Data Cards

DYNAMIC POSITION ACCURACY

POINT	SURVEYED POSITION	DISPLAYED POSITION	STATIONS	ALTITUDE (FEET MSL)	NOTES:

Card 45: Dynamic Position Accuracy Data Cards (Continued)

DYNAMIC POSITION ACCURACY

DESCRIBE THE LOCATION OF THE ROLLOUT:

SELECTED STATIONS AFTER ROLLOUT ______________________________

DISPLAYED AFTER ROLLOUT __________ __________

SURVEYED SHUTDOWN LOCATION __________ __________

SELECTED STATIONS AT SHUT DOWN ______________________________

DISPLAYED AT SHUTDOWN __________ __________

QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE OMEGA DISPLAYS/CONTROLS:

OMEGA STEERING CUES:

ACCURACY:

Card 45: Dynamic Position Accuracy Data Cards (Continued)

3.4.3. Lane Ambiguity Resolution

3.4.3.1 Purpose

The purpose of this test is to evaluate the response of the OMEGA system to erroneous operator inputs of aircraft position.

3.4.3.2. General

As described in the OMEGA theory section, OMEGA lanes are ambiguous every 1/2 wavelength of the OMEGA LF RF. For the 10.2 KHZ signals, this means the lanes are ambiguous every 8 nm. The ambiguity can be mitigated, through analysis of several of the frequencies, to an ambiguity of approximately 144 nm. Most modern airborne OMEGAs use this technique. In most OMEGAs, inputing a new initial position will cause the OMEGA to begin anew the initialization process, the length of which will partially be based upon the accuracy of the input position. The process will be assumed complete when the OMEGA posts an operator alert that the system is navigating.

3.4.3.3. Instrumentation

A stop watch and data cards are required for this test, a voice recorder is optional.

3.4.3.4. Data Required

For each erroneous own aircraft position input to the OMEGA, record the input error, time for an initialized discrete to be posted, INS displayed latitude and longitude and OMEGA displayed latitude and longitude.

3.4.3.5. Procedure

Prior to the test flight, determine the latitude and longitude at which the test will be conducted. The test will be performed using errors in north-south and east-west positions of + 5, 10, 20, 40, 80, 110 and 150 nm. Convert the nm errors to latitude and longitude errors using equation (26). The INS will be used for a comparison with the OMEGA derived position. To correct for INS drift prior to the test, the INS must be updated using the OMEGA derived position. Next add the latitude and longitude errors to the displayed OMEGA position, enter this new latitude and longitude as an OMEGA initialization position and start the stop watch. Record the elapsed time and INS displayed latitude and longitude when the system discrete indicating a navigating OMEGA is displayed. Without updating the INS, repeat for the 10, 20, 40, 80, 110 and 150 nm errors. If a discrete is not displayed after 5 minutes[9] from initialization following any of the erroneous inputs, discontinue the test. No larger errors will then have to be applied.

3.4.3.6. Data Analysis and Presentation

Most modern OMEGA systems are designed to resolve errors of up to 144 nm. The maximum error in initial position which the OMEGA can tolerate and still successfully initialize is bounded between the last successful error input and the failed input. The latitude and longitude of the INS and OMEGA at the time the operator alert is posted should be consistent with the expected errors determined from the OMEGA and INS dynamic aircraft tests. Relate the range of the erroneous inputs resulting in an initialized OMEGA to the possibility of having to reinitialize the OMEGA following a power or system failure and the requirement for an accurate navigational aid following this failure. The presence of a ready discrete with a significant split between the INS and OMEGA derived position should be related to the degraded accuracy and subsequently degraded ability to complete the mission and to safely recover the airplane due to position fixing errors. The halted initialization or degradation of accuracy can be related to the requirement for finding the target or an airfield to land during IMC conditions.

3.4.3.7. Data Cards

A sample data card is provided as card 46.

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[9] May be adjusted for individual systems.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

LANE AMBIGUITY RESOLUTION

[PERFORM AN OMEGA UPDATE OF THE INS, INPUT THE OMEGA ERRORS, START THE STOPWATCH AND WAIT FOR A NAVIGATION READY DISCRETE. RECORD DATA. REPEAT UNTIL THE DISCRETE IS NOT PROVIDED AFTER 5 MIN.]

LAT	LONG	TIME	INS POSIT	OMEGA POSIT

NOTES:

Card 46: Lane Ambiguity Resolution Data Card

3.4.4. Mission Utility and Integration

3.4.4.1. Purpose

The purpose of this test is to assess the utility of the OMEGA system as a position fixing navigation aid and the integration of the OMEGA with the other aircraft avionics, controls and displays.

3.4.4.2. General

As a position fixing system with a long integration time, the primary purpose of the OMEGA is to provide position updates to the DR system (the INS is the sample system here); however, a limited display of OMEGA information integrated into the other aircraft displays is desired. Since OMEGA updates of the INS are expected, the process should be easily performed in a tactical environment. The accuracy of the OMEGA must be consistent with navigation requirements during long range ingress to the target area for an attack aircraft and for station keeping and return to base for a fighter. For the purposes of this sample test procedure, the test aircraft will be an attack aircraft equipped with an air-to-ground radar and an INS that has an OMEGA update mode.

3.4.4.3. Instrumentation

Data cards are required for this test. A voice recorder is highly recommended.

3.4.4.4. Data Required

Record qualitative comments concerning the utility of the OMEGA position fix as an update to the INS. Record comments concerning the accuracy of the OMEGA update as an aid for navigating to and determining the position of the target accurately enough to enable a radar acquisition of the target. Record comments concerning the utility and integration of the OMEGA navigation data displays and the controls necessary for performing an OMEGA update during a mission relatable ingress to the target area. Record as notes a description of the weather conditions.

3.4.4.5. Procedure

Select a mission relatable target in the test area that allows for a 35 to 40 nm ingress to the target location. Select several waypoints inbound to the target. While navigating from the home airfield to the initial waypoint, perform OMEGA/INS updates and assess the utility of the update controls and OMEGA displays for ferry navigation. Descend to a low altitude of approximately 500 feet AGL if safety permits and set an airspeed near the sea level limit of the test aircraft. Head inbound to the target and select a radar mapping mode with at least a 40 nm scale and a wide scan pattern useful for radar mapping. Following the updated INS and radar cues, fly inbound to the target, passing over the waypoints along the route. Once the target is acquired on radar, turn outbound and fly the reverse route to the initial point. Perform another OMEGA update during the reverse route. Use a voice recorder or write down comments after each run. Care should be taken not to become distracted with recording data to allow the best overall qualitative evaluation.

3.4.4.6. Data Analysis and Presentation

Relate the utility of the OMEGA/INS update controls and accuracy to the requirement for suitable position information for finding the target on radar and for long range navigation ferry flights. The updates should be quickly and easily performed in a high workload IMC navigation or attack ingress environment.

3.4.4.7. Data Cards

A sample data card is provided as card 47.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

OMEGA MISSION UTILITY AND INTEGRATION

[AFTER TAKEOFF, CLIMB TO _____ FEET MSL AND SET ___KIAS, PERFORM AN OMEGA UPDATE AND USE OMEGA INFORMATION TO NAVIGATE TO THE INITIAL POINT, ASSESSING THE UTILITY OF THE OMEGA'S ACCURACY AND DISPLAYS FOR IMC NAVIGATION. DESCEND TO ___ FEET AGL AND SET ___KIAS AT THE INITIAL WAYPOINT. SET A 40 NM RADAR SCALE AND A _____° SCAN ANGLE LIMIT. SEARCH FOR THE TARGET ON RADAR WHILE NAVIGATING TO THE WAYPOINTS. WHEN THE RADAR TARGET IS ACQUIRED, RETURN TO THE INITIAL POINT USING THE RECIPROCAL FLIGHT PATH.]

INITIAL WAYPOINT 1 POSITION __________ __________

WAYPOINT 2 POSITION __________ __________

WAYPOINT 3 POSITION __________ __________

NOTES:

Card 47: OMEGA Mission Utility and Integration Data Card

3.4.5. Introduction to Advanced OMEGA Navigation System Test Techniques

As mentioned in Chapter 1, only the most rudimentary form of the OMEGA navigation system test techniques are presented in this book. Chapter 1 details the reasons for this format; however, in many applications, more rigor, accuracy and documentation of results are required. Table V outlines additional instrumentation and assets which are typically applied in these more advanced tests. The purpose of this table is merely to emphasize the existence of these advanced techniques. Further, this list is not exhaustive. Many innovative uses of assets and instrumentation exist. It is hoped that the examples provided leave the reader with a taste of how the test can be made more rigorous through the judicious use of instrumentation. In application; the user must refer to the more advanced documents referenced in Chapter 1 or solicit help from more experienced testers.

Table V: Additional Assets or Instrumentation for use in Advanced OMEGA Navigation System Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Initialization.	Digital recording of OMEGA derived position, site selections, and operator actions. Precisely surveyed initialization location. Validated OMEGA receiver located close to the test aircraft. Precise documentation of weather and propagation effects.	The entire initialization is recorded, allowing isolation of the causes of a slow or failed initialization. The test OMEGA initialization is compared to a second OMEGA with known characteristics. When both have initialization problems, correlation is made with the recorded weather and known propagation anomalies. The initialization is correlated to operator selections. The first position is compared to the known alignment location.
Dynamic Position Accuracy.	Digital recording of time stamped space positioning data, OMEGA derived position and site selections, and operator actions. Video recording of the time stamped display. Precise documentation of weather and propagation effects.	The profile is flown without the necessity of surveyed point flyovers. Space positioning data and aircraft dynamics are continuously recorded and later compared to OMEGA derived values. If derived from a range, the profile is often constrained geographically. Recently, Global Positioning System (GPS) data can be used with sufficient accuracy to avoid constricting the profile. The time stamped display video is compared to the OMEGA data to check for inconsistencies caused by the manipulation of the OMEGA data and then its display. If problems are noted, the errors are first compared to known weather and propagation problems. The OMEGA selection of ground sites is compared to the expected site use (based upon the time stamped aircraft location) for inconsistencies.

Table V: Additional Assets or Instrumentation for use in Advanced OMEGA Navigation System Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Lane Ambiguity Resolution.	Digital recording of time stamped space positioning data, OMEGA derived position and site selections, and operator actions. Video recording of the time stamped display. Precise documentation of weather and propagation effects.	The precise aircraft location at the time the erroneous position error is entered is compared directly to determine the position error at each initialization. Elapsed time is derived at the time the initialization is complete and the position is compared to the known aircraft location. The displayed positions and operator feedback are compared to the time stamped OMEGA parameters. When unexpected problems are noted in lane ambiguity resolution, the errors are first compared to known weather and propagation problems.
Mission Utility and Integration.	Digital recording of time stamped space positioning data, OMEGA derived position and operator actions. Video recording of the time stamped display. Time stamped, digital recording of all navigation data passed to other aircraft systems.	This test requires the largest amount of data to completely document the results. It is during this test that most of the unexpected problems are found. In anticipation of having to document these deficiencies, maximum instrumentation and range support are sometimes brought to bear in case unforseen data are required in post-flight analysis.

3.5. Coupled Global Positioning System/Inertial Navigation System

3.5.1. General

The Global Positioning System (GPS) was designed to provide an unlimited number of users with continuous, worldwide, all-weather, common grid, three-dimensional, positional information as well as a highly accurate source of time and doppler based velocity information. GPS consists of the three segments: [Ref. 48:p. I-3, I-4].

✓ Space Segment
✓ Control Segment
✓ User Segment[10]

3.5.2. Space Segment

The space segment consists of a constellation of 18 operational satellites with three on-orbit spares. The satellites are spaced in six planes inclined at 55° with three or four satellites per plane. The satellites travel in 10,900 nm circular orbits with a period of twelve hours. Each satellite transmits a continuous information stream including its own satellite ephemeral data[11], atmospheric propagation correction data and satellite clock bias information. The data are transmitted on two frequencies, 1575.42 MHZ and 1227.6 MHZ, known as L1 and L2, respectively. Two frequencies are used so that an algorithm can be applied to correct ionospheric propagation effects. [Ref. 10].

3.5.3. Control Segment

The Control Segment consists of five Monitor Stations, three Uplink Stations and a single Master Control Station as depicted in figure 10. The Monitor Stations passively track each satellite within their view and collect ranging data using the satellite signal. The information is passed to the Master Control Station in Colorado Springs, Colorado, where updated satellite ephemeral data, clock bias and ionospheric propagation corrections are calculated. These new parameters, unique to each satellite, are then uplinked to the constellation via the three Uplink Stations. The Control Segment uses a frequency of 2227.5 MHZ for downlink from the satellite and 1783.74 MHZ for uplink to the satellite. [Ref. 48:p. I-6, Ref. 11].

3.5.4. User Segment

The User Segment consists of the various GPS equipment carried onboard the user platforms. GPS equipment may be carried on ground vehicles, ships, by individual persons and on aircraft. This document will concentrate on the testing of aircraft-based user equipment.

A typical aircraft installation includes an antenna and associated cabling/coax, a receiver, which converts the incoming RF signals to digital messages, a processor unit and a display. The receiver and processor are often contained within the same physical unit or may be placed on a single card for inclusion in another unit.

The receiver and processor accept the satellite ephemeral data and use it to calculate a precise location for the satellite. The satellite sends the exact time of transmission of each message. The processor uses the exact time of transmission and reception of the signal, corrects the signal, scales the difference in time by the propagation rate, corrects ionospheric propagation effects and thus calculates the unambiguous range to the satellite. Knowledge of the satellite location at the time of transmission thus provides a sphere on which the user equipment antenna must be located. By performing the same calculations for three satellites, an unambiguous position upon the surface of the earth is calculated. By adding a fourth satellite's information, a three-dimensional position is provided. [Ref. 10].

[10]This document will discuss the testing of airborne user equipment only. It is assumed that the space and control segments are fully developed and their performance quantified.

[11]Ephemeral data include a complete description of the orbital parameters of the satellite and thus allow the calculation of the precise location of the satellite at any time.

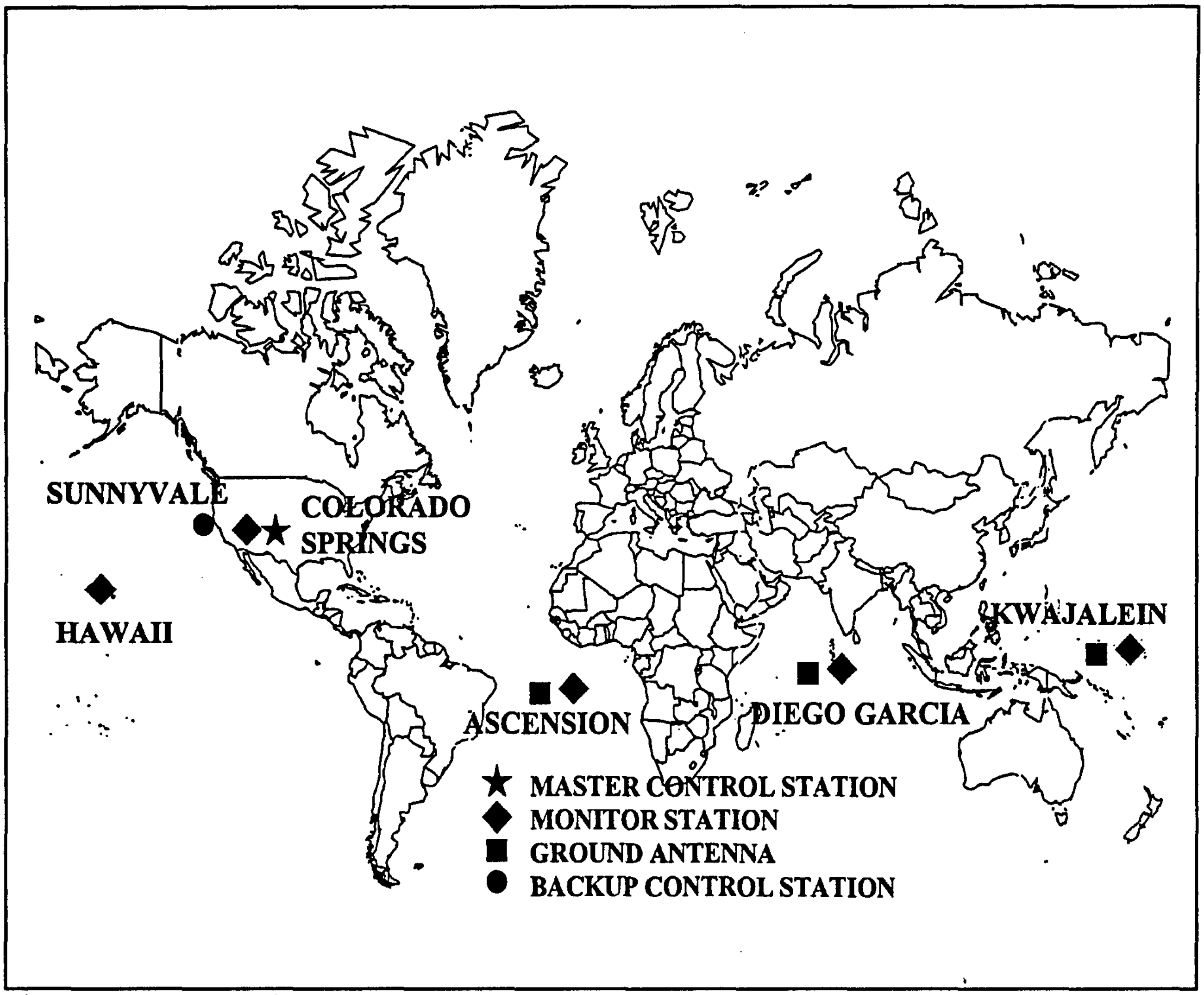


Figure 10: Control Segment Components

For airborne applications, the receiver/processor is designed to simultaneously receive, decode and use the signals from four to eleven different satellites simultaneously. In this way, the required signals for three-dimensional position calculations can always be tracked even when satellites rise and fall from view.

In addition to range, the ephemeral data, aircraft location and doppler shift of the GPS signal are used to calculate platform translation velocities. A very precise time source is also available from the GPS system. [Ref. 10]. The GPS concept is graphically depicted in figure 11.

3.5.5. Selective Availability

The GPS-generated position is typically very accurate. It is so accurate that its position is adequate for targeting of many weapons. During the design of the GPS system, it was the stated intent of the U. S. DoD not to make targeting grade accuracy available to everyone. The GPS signal is thus degraded somewhat, requiring special cryptographic equipment to attain the full system accuracy. This function is called the Selective Availability (SA) system. To obtain the SA accuracies, cryptographic hardware and a special code, called the P code, which is periodically changed, must be loaded.

3.5.6. Accuracies

The GPS, with SA applied, is designed to provide 16 m Spherical Error Probable (SEP) accuracy. SEP is a sphere with radius equal to the 50% error bounds. A sphere is used vice a circle since the GPS is capable of three-dimensional positioning. Without SA applied, the GPS

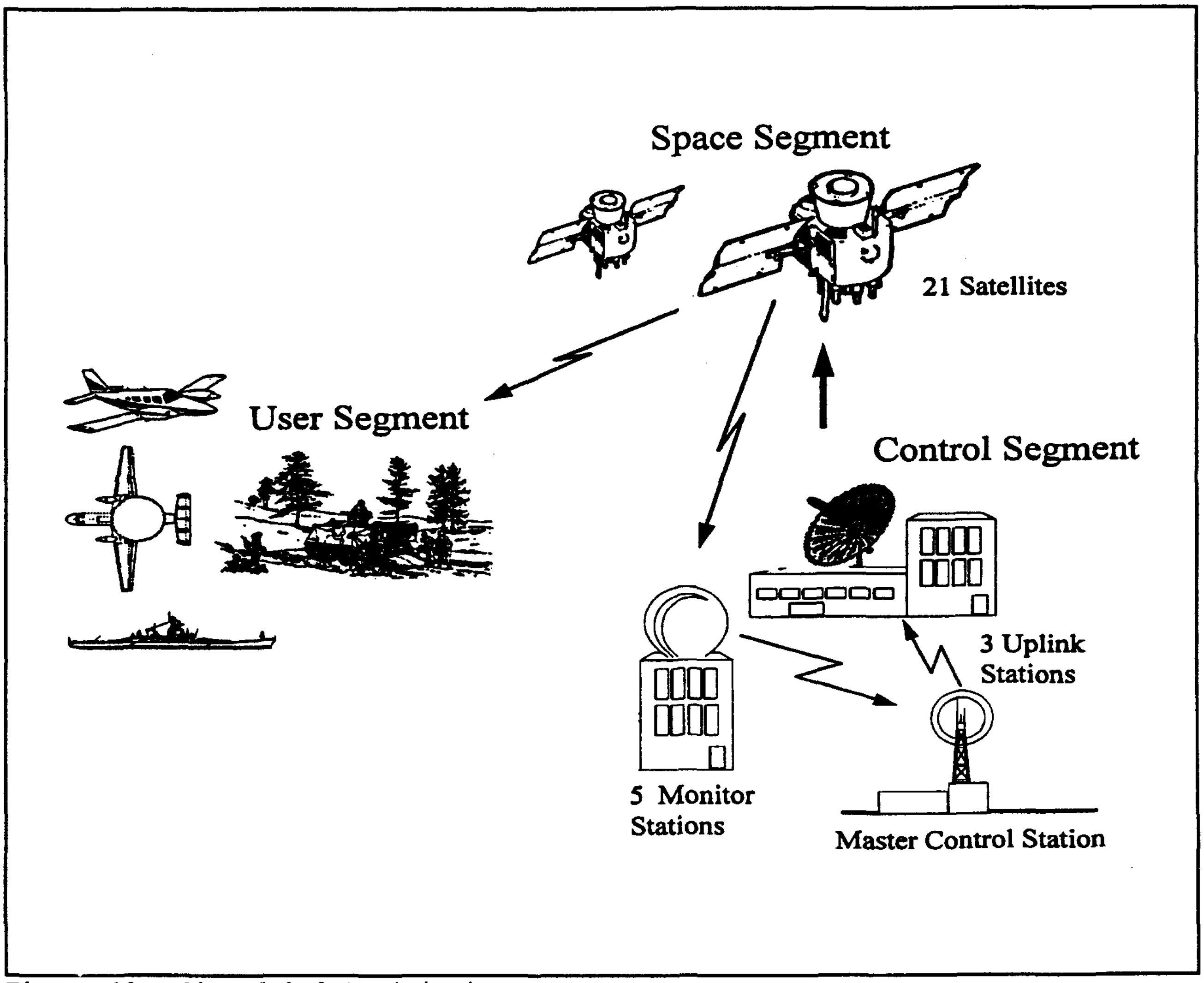


Figure 11: The Global Positioning System Concept

is designed to provide 100 m SEP accuracies. It is important to note that the non-SA accuracy is completely arbitrary and totally dependent upon the desires of the satellite controllers. [Ref. 48:p. I-10]. GPS time is typically accurate to 100 nanoseconds and velocity to 0.1 m/sec. [Ref. 10].

GPS user equipment performance is affected by seven factors [Ref. 10]:

✓Vehicle Dynamics
✓Multipath Effects
✓Nominal System Errors
✓Vehicle Environment
✓Satellite Constellation Geometry
✓Ionospheric/Tropospheric Effects
✓Hostile Environment

These test procedures will specifically isolate and quantify vehicle dynamics and multipath effects. Since these tests are performed on the GPS, as installed in the aircraft, the nominal system errors and errors due to the vehicle environment will be indistinguishable and will be quantified as a group. To date, a full constellation of GPS satellites are airborne and thus, an adequate set of satellites should always be visible. If problems are noted during the test, it may become necessary to either isolate or eliminate the geometry effects. This is readily accomplished since the satellite ephemeral data are openly available. A number of software programs are available for accomplishing this task. As an example, the author was provided, free of charge, with a set of GPS simulation and utility programs which included algorithms for calculating GPS satellite visibility as well as GDOP predictions [Ref. 51: p 3]. As long as the system does not exhibit deficiencies during the tests to be described, it will not be necessary to check for satellite constellation geometry problems. Ionospheric/tropospheric effects are corrected within the space segment. For the purposes of this test, it will be assumed that the space segment corrections are functioning appropriately. The user equipment hostile environment includes the effects of hostile jamming of the satellite signal. The effects of intentional, hostile jamming will not be considered in this document.

3.5.7. Precise Space Positioning Instrumentation

Due to the extreme accuracy of the GPS system, GPS testing requires an instrumentation system which is also extremely precise. Target location must be known to at least the accuracy to which the tester is attempting to validate the system. Two classes of trackers are usually used to obtain accuracies on the order of a few feet, laser trackers and theodolite trackers.

Laser-based trackers are highly precise, but are severely limited in range. The limited range is exacerbated by high humidity or the presence of any visible moisture. Typically, the technique is no longer useful when the aircraft is greater than 15 nm from the laser. Most laser trackers provide both a precise bearing to the target as well as range. Ranging is done by pulsing the laser energy in a fashion similar to radar. Given a surveyed location of the laser tracker, the azimuth and elevation of the laser beam and the target range, the target latitude and longitude is calculated. Accuracies on the order of two to three feet are typical. With accuracies less than the dimensions of the aircraft, it is necessary to specify the location on the aircraft which is to be tracked. This is usually done by installing a small array of mirrors in the form of a hemisphere, on the aircraft. The laser then tracks this set of mirrors.

Highly accurate positioning may also be derived using a network of theodolite trackers. Conceptually, a theodolite is merely a telescope. The telescope is mounted on a precisely surveyed location. An operator places optical crosshairs over a chosen location on the aircraft. The precise azimuth and elevation angle of the telescope apparatus is then measured and thus a precise, three-dimensional line through the target location is known. The theodolites are used in arrays with several simultaneously providing lines of bearing, thus defining the location of the target. The maximum useful range is restricted by any condition which may affect optical visibility as well as by the geometry within the theodolite array. Accuracy is a function of the range from each theodolite and geometry with the best accuracy occurring when the lines of bearing from each theodolite used are approximately at right angles. Typical arrays allow coverage of a 15 to 20 nm area.

Most test ranges use the precise space positioning data as an input to a computer algorithm which then is used to calculate precise groundspeed and course. The calculations may be done off-line or in real time. For the purposes of developing the sample test techniques, it will be assumed that the calculations are performed real time and available to the test aircraft while the test is being performed.

Since the GPS position and the range derived space positioning data tend to be so accurate, it is absolutely necessary for the positions derived from both sources to use a common geodetic grid system and reference point. Until recently, the errors induced by shifting from one system to another were typically small enough that they were not significant relative to the system errors. With the advent of systems like GPS, the geodetic system differences can cause significant apparent errors in the GPS under test, when in fact, none exist. A geodetic set, common to the system under test, must be used, or corrections for the differences must be made during data reduction.

3.5.8. Sample System

The procedures to follow will be developed to test a sample system which includes an antenna mounted upon the top of a tactical aircraft, behind the cockpit. The receiver and processor are a single box internal to the aircraft. The positions, velocities and time, generated by the GPS, are passed to a second processor which integrates the GPS navigation information with the output of the aircraft INS described earlier. The GPS thus provides a continuous update to the INS position as well as an additional source of velocities. These inputs are combined with the INS solution using standard filters to produce a single navigation solution. This solution is more accurate than either the stand-alone INS or GPS is capable of developing.

In most cases, a Kalman filter is used in the GPS to develop the smoothed positions and in the INS to observe the platform rates, which are then used in the DR solution. The sample system uses a single, 18-state Kalman filter, combining the inputs of both. This arrangement has the advantage of exploiting the benefits inherent in both a highly precise position fixing system and a DR system. However, it also has the disadvantage that it retains the problems inherent in both systems. Therefore, it is necessary to test the system for all the weaknesses discussed in the INS testing section as well as the new problem areas inherent in the GPS system.

If either the GPS or INS inputs are not available, the algorithm continues to produce a navigation solution using the single source of information. The missing information is calculated as needed. The outputs to the operator are similar; however, the accuracies are limited to approximately that of the stand-alone INS or GPS as applicable.

The GPS/INS integration described here is an example of a coupled position fixing/DR system. It will be seen that the test techniques are logically a combination of those used for the sample INS and OMEGA systems used as the examples of pure position fixing and DR systems. The Preflight and Built-In Tests, and the Controls and Displays tests provided in section 3.2 are applicable as written to the sample GPS/INS.

3.6. GLOBAL POSITIONING SYSTEM TEST TECHNIQUES

3.6.1. Initialization and Alignment

3.6.1.1. Purpose

The purpose of this test is to assess the coupled GPS/INS initialization and alignment procedures for their utility for quickly reaching full navigation status, with a minimum of operator time and attention, and the effect that these procedures have upon the set-up sequence of other aircraft systems.

3.6.1.2 General

Since the GPS/INS used for the sample unit is a coupled system, several different configurations must be tested:

1. Fully coupled INS with GPS, initial latitude and longitude provided, P Code installed, on the ground.
2. GPS alone, initial latitude and longitude provided, P Code installed, on the ground.
3. GPS alone, initial latitude and longitude not known, P Code installed, on the ground.
4. Repeat 1 through 3 with the P code not installed.
5. INS alone.
6. Repeat 1 through 5 using an airborne alignment.

Initialization of the GPS requires two phases. In the first phase, synchronization of the GPS user equipment clock with satellite time is performed. In the second phase, the signal from each satellite is acquired, tracked and decoded to calculate a navigation solution. The initialization process typically takes several minutes to perform.

Initialization indications usually include a graphical display as the first satellite and each subsequent satellite signal is acquired. A quality number is provided as the signal for each satellite is decoded. Usually, the display of the first satellite coincides with the completion of the clock synchronization. The quality numbers will typically vary as the quality of the satellite signal changes, such as may occur as the satellite leaves the visible horizon. A separate quality number is usually provided which indicates the state of the complete GPS navigation solution. This number may be in terms of a confidence level with little physical significance or may directly relate to the expected positional accuracy. A discrete is usually provided which indicates that the system is providing the expected navigational accuracy. This will be considered the completion of the initialization phase for the sample system. [Ref. 10].

As the GPS begins the initialization process, it uses the user-entered or previously stored GPS location, approximate time and the stored library of satellite ephemeral data to determine which satellites are within view and which provide the optimal geometry for the navigation calculations. GDOP is as important to GPS as it is for OMEGA. If the location is significantly incorrect, the initialization takes longer since the GPS must search for which satellites are within view and which are best to minimize GDOP. The test is performed using a known initial location and then performed again under the assumption that the operator knows little about the initial location. The initial position location error magnitude choice is a bit arbitrary, but 300 nm will be used for this test. This number was chosen under the assumption that the operator can be expected to know the correct location to within five minutes of latitude.

The INS initialization and alignment procedures are outlined in the navigation theory section. During a fully coupled initialization and alignment, the highly precise, GPS-derived, initial position is made available to the INS for an initial alignment position. As long as the initial position is known prior to start and the correct position entered into the INS during initialization, this coupling makes little difference in the time required for initialization and alignment. Waiting for the GPS to initialize typically requires more time than is saved in the alignment, and thus, most systems begin the INS procedures concurrent with the GPS and later allow the GPS position to be used to update the INS position after the GPS alignment is complete. The sample system uses this technique.

In most systems, the presence or absence of a P code makes little difference to the GPS initialization process. In the sample system, the only difference is the time required to transfer the code from the cryptographic unit's memory and the BIT on the unit itself. These processes occur during and before the BIT process and thus are timed during the Navigation System Preflight and BIT tests discussed earlier. However, for completeness, the initializations will be repeated without the presence of the P code, to ensure there is no difference in the time required.

All of the ground initialization and alignment configurations can be performed while airborne. Airborne alignment may be required after a very rapid alert launch or after losing the alignment while airborne. Typically, the GPS initialization times will be similar for both the airborne and ground cases. The INS will take significantly longer to align while airborne for the case of the INS alone. The required time is significantly reduced when the GPS is coupled due to the presence of a continuously updating, highly precise fix. The time will still be greater than the ground alignment time.

Initialization of the INS includes providing the system with position and orientation inputs from which to reference the alignment. Alignment involves first leveling the platform and then orienting the true north axis to the geographic true north. Alignment is usually serially dependent upon initialization. The set up of other aircraft systems is sometimes partially dependent upon the presence of an INS alignment. As an example, geostable tactical displays require navigation input to operate. While alignment is taking place, the pilot will have many other tasks to perform, such as turning on other systems, starting the aircraft, attempting to obtain tactical SA, or putting on his or her flight gear and strapping into the aircraft seat. A quick and easy alignment process requiring a minimum of operator inputs and attention is essential.

Several factors can affect the INS initialization and alignment process. Navigation control and display issues, addressed earlier can affect the time and effort required for the entry of the initialization parameters. Outside air temperature can affect alignment time. The colder the temperature of the INS, the longer the alignment will take. Motion of the aircraft can slow the alignment process. Actually moving the aircraft, whether by taxiing or towing, usually requires suspending the alignment with an additional penalty of time as the process is resumed. Alignment latitude can affect the alignment time. An alignment often will take longer at higher latitudes, with a significant delay above 70° latitude. Ship-based alignments usually take 50% to 100% longer than shore-based alignments. Most systems require four to ten minutes for the shore-based initialization and alignment procedure. A wide variance of times can be obtained depending upon the factors listed above and so it is important to carefully record the conditions of the alignment. Since the alignment process takes a significant amount of time, a status indication should be provided to give the pilot an indication of the time left to a complete alignment and to provide feedback that the process is proceeding normally.

Ideally, the system should be checked over the entire range of expected alignment conditions. Checking all conditions is rarely possible. A wide range of temperature conditions can require much travel, time, or expensive test chambers. Testing the alignment times over a variety of locations also requires expensive travel. This test procedure will be performed at the given test location and current atmospheric conditions providing a spot check of one possible condition. If a choice is available; however, it is always best to test at the expected operational conditions and secondarily at the extremes of the expected range of parameters. For this technique, ship-based alignments will not be discussed. The ship-based test technique is essentially the same except that automatic recording of the continuously changing position and orientation parameters is required.

3.6.1.3. Instrumentation

A stop watch, thermometer (suitable for measuring outside air temperature) and data cards are required for this test. A voice recorder is optional.

3.6.1.4. Data Required

For each of the initialization and alignment configurations, record the time required to input the GPS and INS initialization parameters as appropriate. Record qualitative comments concerning the ease and complexity of the data entry. Note if the initialization process interferes significantly with the start-up and turn-on procedures for the entire aircraft. For all of the configurations, record the surveyed latitude and longitude of the aircraft and the position provided to the INS and GPS as part of the initialization process.

For all of the configurations which include the INS, record the actual heading of the aircraft during alignment (if available via an independent source such as a calibrated compass alignment rose), local magnetic variation and outside air temperature. If a compass rose is not available, record the surveyed alignment position, magnetic compass heading (with deviation applied) and magnetic variation. Record a complete description of aircraft motion during the alignment. For the interrupted alignment, record the elapsed time at interrupt, resumption of the alignment and a complete description of the aircraft movement. Include the new surveyed location and aircraft heading. At the completion of the alignment, record the INS displayed latitude and longitude, magnetic heading, true heading, magnetic variation and the total time for the alignment. Note qualitative comments concerning the utility of the INS alignment status indications including the alignment complete indication.

For all of the configurations which include the GPS, record the approximate heading of the aircraft and any obstructions between the GPS antenna and the sky, including buildings, mountains, vehicles, etc. Record the elapsed time and satellite numbers as each satellite is acquired, and if applicable, dropped. Make comments as to the quality number trends for each satellite. The quality numbers should continuously improve until an adequate fix is calculated. Comment on the utility of the GPS initialization displays for determining the status of the initialization.

3.6.1.5. Procedure

Most airfields have a surveyed compass rose which is used for calibrating installed magnetic compasses. The center of the rose is accurately surveyed in latitude and longitude and magnetic headings are marked around the circumference of the rose. When possible, the alignment should be performed at the surveyed rose to provide accurate position and heading truth data. When a compass rose is not available, perform the alignment at any other surveyed location. Most hangars have surveyed parking slots on the ramp. In this case, an estimate of aircraft heading after alignment can be obtained using the magnetic compass with deviation applied. Local area magnetic variation should be obtained from published field charts, approach plates, en route charts, TPCs, etc.

Large obstructions between the aircraft and the sky may affect the GPS initialization by obstructing the view of satellites. Select a location which is representative of the types of obstructions which will be encountered by operational users. Carefully note any and all obstructions in case problems with satellite acquisition are noted. Heading must still be recorded for the GPS-only initialization; however, the accuracy need not be as precise.

Tow the test aircraft to the local compass rose and record the surveyed position, heading and magnetic variation. If a compass rose is not used, record the surveyed alignment location, the magnetic heading as displayed on the back-up magnetic compass with deviation applied and the magnetic variation. Allow the INS to remain OFF for at least one hour before beginning the test to allow the components to cool to ambient temperature. Record the outside air temperature.

Using the procedure published for the GPS/INS, perform a coupled GPS/INS initialization. Record the time required for initialization of both systems along with qualitative comments concerning the ease of the initialization procedures and the extent to which initialization distracts the pilot from turning on the entire aircraft. The GPS synchronization and satellite acquisition will begin automatically after the initialization is performed. The INS initialization must be selected by the operator. Start the clock as the GPS initialization is completed and the satellite acquisition begins; and note the elapsed time upon starting the INS alignment. As the alignment progresses, note the quality of the alignment status indicators and of the alignment complete indication. Note as each satellite is acquired and make general comments about how the quality numbers for each satellite progress. When the alignment is complete, note the total elapsed time, the indicated magnetic and true aircraft heading and the magnetic variation. Completely describe any aircraft motion during the alignment process. Repeat the initialization and alignment test before each test flight.

At least one interrupted alignment should be performed. Begin the alignment process at any surveyed point and then tow or taxi the aircraft to the surveyed compass rose to complete the alignment. Record the parameters described above at both the first and second location. Note the elapsed time at interrupt and again when the alignment is resumed.

Repeat the test with the INS turned off, recording only the parameters related to the GPS. Repeat the test again, but this time, provide the GPS with an initial position which is in error by 300 nm. Next, repeat all three tests with the P code not installed. As the final ground task, perform the test with the GPS turned off, recording only the parameters related to the INS. Ensure that for each test including the INS, that the INS has been off for at least one hour.

Perform the airborne initialization and alignments using each of the five test configurations. Prior to the flight, select a flyover point near the field as discussed in the earlier section on The Flyover Method. Take off with both the INS and GPS secured. Initialize the INS and GPS by turning on the systems, allowing the BIT to run and then by flying over the surveyed point and inputing the flyover latitude and longitude as the present position. Start the clock as the point is entered. As on the ground, this is the time that the GPS begins its synchronization and acquisition process. Note the elapsed time when the INS alignment mode is manually selected. Most systems, including the sample system, require a maximum amount of straight and level flying as the INS aligns. The GPS is typically affected little by maneuvering as long as the antenna can maintain satellite visibility. Since the first test is coupled, perform this portion while maintaining a maximum of straight and level flying. Record the elapsed time as each new satellite is acquired and as the initialization is complete. Record as notes the general trends and the satellite quality numbers as each satellite is tracked and the navigation solution converges.

Upon completing the GPS initialization, the sample system uses the GPS position to update the INS position. The final position accuracy must be measured after the alignment. The expected accuracy of the position provided by the GPS makes the measurement problematic while airborne, requiring that the goal of minimum outside instrumentation be violated. Since the required accuracy must be on the order of feet to validate the accuracies of the coupled system, only two sources are typically available. The first is via laser-based tracking and the second is by theodolite. These trackers were discussed in the GPS theory section.

Upon completion of the airborne alignment, also note the total elapsed time, the indicated magnetic heading, INS derived true heading and the magnetic variation. Completely describe any aircraft maneuvers during the alignment process.

Repeat the test with the INS turned off, recording only the parameters related to the GPS. Repeat the test again, but this time, provide the GPS with an initial position which is in error by 300 nm. Next, repeat all three tests with the P code not installed. As the final task, perform the test with the GPS turned off, recording only the parameters related to the INS.

3.6.1.6. Data Analysis and Presentation

Relate the time required to perform the ground INS and GPS initialization, the complexity of the procedure and the overall operator intensity as a distraction to the pilot as he or she attempts to turn on other systems, straps into the aircraft, starts the engines and gains SA. Compare the initialized aircraft position at the start of the alignment (input by the operator) to the position at the time the alignment is complete. There should be no INS drift during the alignment process and the GPS position should be the same. Apply the actual aircraft heading on the compass rose and the local magnetic variation to equation (21) to obtain true heading. Where a compass rose is not used, apply the magnetic back-up compass heading with deviation applied and local magnetic variation to equation (21) to obtain true heading. The accuracy of the truth data will be degraded. Compare the true heading, magnetic heading and magnetic variation provided by the INS at the time of the alignment to the actual values and relate the difference to the quality of the alignment, the effect that inaccuracies will have upon positional drift and the utility of INS headings for accurately navigating in a mission relatable ingress and attack.

Relate the quality of the status indicator, including the alignment complete indication, as a guide to how long the alignment has left to complete, as a source of confidence that the alignment is progressing normally and as an indicator that the aircraft has an operating navigation system with which to launch. Relate this to the time requirements and stress of an alert launch. Compare the alignment time to the time requirements of an alert launch and to the specification at the ambient temperature recorded during the test. If extreme variation in the alignment time and quality is noted during alignments where aircraft motion is a factor (for instance while maintenance personnel are climbing on the airplane) relate it to the requirement for preflight trouble shooting before aircraft launches. Compare the time for a suspended alignment less the actual time the alignment was suspended, to the time for an uninterrupted alignment. Relate any extreme variation to the requirement to occasionally move aircraft on a crowded ramp during a mass alert sortie.

Relate the time and effort to perform the airborne INS and GPS initialization, the complexity of the procedure and the overall operator intensity as a distraction to the pilot as he or she attempts to fly the airplane on a rapid alert launch. Relate any degradation in the GPS initialization or the INS alignment caused by essential maneuvering and speed changes to the necessity to perform normal navigation after the alert launch. Compare the total time for the GPS to reach full capability and the satellite acquisition times to the times recorded for the ground tests. There should be only minor differences for the airborne initialization. The total INS alignment time should meet the specified requirement and should allow the INS to become aligned before it becomes essential to the mission. This time is typically during the final phases of an attack, where weapons are being targeted.

Compare the GPS-derived position, course, groundspeed and altitude to the truth data. The position and altitude should meet the accuracy requirements as outlined in the theory section. The course and groundspeed should be accurate enough to allow degraded navigation while awaiting completion of the inflight alignment.

Compare the position, course, groundspeed and altitude after the GPS/INS is fully aligned to the specified requirements. Typical position and altitude requirements are discussed in the theory section. Typical course and groundspeed requirements are within the resolution of the heading display and a few knots.

Relate the same parameters for the GPS-only configuration to the necessity to perform the mission after the INS has failed following a rapid alert launch which occurs before either system is ready. For the INS only configuration, relate the parameters to the need to perform the mission after the GPS fails under the same conditions.

Relate the P code absent test conditions to the necessity to perform the mission after loss of the code or after a launch from a location where the code is not available.

3.6.1.7. Data Cards

Sample data cards are provided as cards 48 and 49. For the condition of the GPS turned off and the INS alignment performed independently, use data card 38 from the INS test techniques section. Reuse cards 48 and 49 when the P code is not installed.

CARD NUMBER ___

GPS/INS COUPLED INITIALIZATION AND ALIGNMENT

ALIGNMENT LOCATION __________ __________ P CODE YES/NO

ALIGNMENT HEADING __________ MAGNETIC VARIATION __________

[ALLOW THE AIRCRAFT TO COLD SOAK FOR ONE HOUR. PERFORM A NORMAL COUPLED GPS/INS INITIALIZATION.]

INITIALIZATION EASE/COMPLEXITY/EFFECTS UPON OTHER TURN ON AND START PROCEDURES:

INITIALIZATION TIME __________

[WHEN THE POSITION IS INPUT INTO THE GPS AND INS, START THE STOP WATCH, THEN START THE ALIGNMENT.]

ELAPSED TIME AT START OF ALIGNMENT __________

OUTSIDE AIR TEMPERATURE __________

[NOTE THE ELAPSED TIME AS EACH SATELLITE IS ACQUIRED.]

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

NOTE QUALITATIVE COMMENTS CONCERNING THE SATELLITE QUALITY NUMBER PROGRESSION AND UTILITY OF THE GPS READY INDICATIONS:

COMPLETELY DESCRIBE ANY OBSTRUCTIONS BETWEEN THE GPS ANTENNA AND THE HORIZON:

TIME WHEN THE GPS READY INDICATION IS PROVIDED __________

FINAL GPS POSITION WHEN READY FOR NAV __________ __________

Card 48: Initialization and Alignment Ground Test Data Cards

CARD NUMBER ___

GPS/INS COUPLED INITIALIZATION AND ALIGNMENT

COMPLETELY DESCRIBE ANY AIRCRAFT MOVEMENT:

[IF THE AIRCRAFT IS TURNED OR TOWED, NOTE THE TIME OF THE SUSPENDED ALIGNMENT AND THE TIME OF THE RESTART.]

SUSPENDED __________ RESTART __________

DESCRIPTION OF AIRCRAFT MOVEMENT DURING SUSPENDED ALIGNMENT:

FOR THE NEW AIRCRAFT LOCATION:

COMPLETELY DESCRIBE ANY NEW OBSTRUCTIONS BETWEEN THE GPS ANTENNA AND THE HORIZON:

ALIGNMENT LOCATION __________ __________

ALIGNMENT HEADING __________ MAGNETIC VARIATION __________

TIME TO COMPLETE THE ALIGNMENT __________

QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE ALIGNMENT STATUS AND THE ALIGNMENT COMPLETE INDICATORS:

WHEN THE ALIGNMENT IS COMPLETE:

DISPLAYED INS LOCATION __________ __________

DISPLAYED MAGNETIC HEADING __________

DISPLAYED TRUE HEADING__________

DISPLAYED MAGNETIC VARIATION __________

WERE OTHER SYSTEMS/PROCEDURES WAITING ON THE INITIALIZATION OF THE GPS OR INS, OR THE INS ALIGNMENT? IF SO, DESCRIBE:

Card 48: Initialization and Alignment Ground Test Data Cards (Continued)

CARD NUMBER ___

GPS INITIALIZATION (CORRECT POSIT AVAILABLE)

ALIGNMENT LOCATION __________ __________ P CODE YES/NO

ALIGNMENT HEADING __________ MAGNETIC VARIATION __________

[PERFORM A NORMAL GPS INITIALIZATION.]

INITIALIZATION EASE/COMPLEXITY/EFFECTS UPON OTHER PROCEDURES:

INITIALIZATION TIME __________

[WHEN THE POSITION IS INPUT INTO THE GPS, START THE STOP WATCH]

ELAPSED TIME AT START OF TIME SYNC __________

[NOTE THE ELAPSED TIME AS EACH SATELLITE IS ACQUIRED]

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

NOTE QUALITATIVE COMMENTS CONCERNING THE SATELLITE QUALITY NUMBER PROGRESSION AND UTILITY OF THE GPS READY INDICATIONS:

COMPLETELY DESCRIBE ANY OBSTRUCTIONS BETWEEN THE GPS ANTENNA AND THE HORIZON:

TIME WHEN GPS READY INDICATION PROVIDED __________

FINAL GPS POSITION WHEN READY FOR NAV __________ __________

WERE OTHER SYSTEMS/PROCEDURES WAITING ON THE INITIALIZATION OF THE GPS? IF SO, DESCRIBE:

Card 48: Initialization and Alignment Ground Test Data Cards (Continued)

CARD NUMBER ___

GPS INITIALIZATION (CORRECT POSIT NOT AVAILABLE)

INITIALIZATION LOCATION __________ __________ P CODE YES/NO

INITIALIZATION HEADING __________ MAGNETIC VARIATION __________

[PERFORM A NORMAL GPS INITIALIZATION USING AN INITIAL POSIT IN ERROR BY 300 NM.]

ERRONEOUS INITIAL POSIT __________ __________

INITIALIZATION EASE/COMPLEXITY/EFFECTS UPON OTHER PROCEDURES:

INITIALIZATION TIME __________

[WHEN THE POSITION IS INPUT INTO THE GPS, START THE STOP WATCH.]

ELAPSED TIME AT START OF TIME SYNC __________

[NOTE THE ELAPSED TIME AS EACH SATELLITE IS ACQUIRED.]

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

NOTE QUALITATIVE COMMENTS CONCERNING THE SATELLITE QUALITY NUMBER PROGRESSION AND UTILITY OF THE GPS READY INDICATIONS:

COMPLETELY DESCRIBE ANY OBSTRUCTIONS BETWEEN THE GPS ANTENNA AND THE HORIZON:

TIME WHEN GPS READY INDICATION PROVIDED __________

FINAL GPS POSITION WHEN READY FOR NAV __________ __________

WERE OTHER SYSTEMS/PROCEDURES WAITING ON THE INITIALIZATION OF THE GPS? IF SO, DESCRIBE:

Card 48: Initialization and Alignment Ground Test Data Cards (Continued)

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

GPS/INS COUPLED INFLIGHT INITIALIZATION AND ALIGNMENT

[INITIALIZE FOR A FLYOVER UPDATE AND ALIGNMENT.]

FLYOVER POINT LOCATION __________ __________ P CODE YES/NO

ALIGNMENT HEADING __________ MAGNETIC VARIATION __________

INITIALIZATION EASE/COMPLEXITY, EFFECTS UPON OTHER PROCEDURES:

INITIALIZATION TIME __________

[NOTE ANY HEADING/SPEED/ALTITUDE CHANGES WITH TIME.]

CHANGE __________ TIME__________ CHANGE __________ TIME__________

CHANGE __________ TIME__________ CHANGE __________ TIME__________

[WHEN THE POSITION IS INPUT INTO THE GPS AND INS, START THE STOP WATCH, THEN START THE ALIGNMENT.]

ELAPSED TIME AT START OF ALIGNMENT __________

OUTSIDE AIR TEMPERATURE __________

[NOTE THE ELAPSED TIME AS EACH SATELLITE IS ACQUIRED.]

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

NOTE QUALITATIVE COMMENTS CONCERNING THE SATELLITE QUALITY NUMBER PROGRESSION AND UTILITY OF THE GPS READY INDICATIONS:

COMPLETELY DESCRIBE ANY OBSTRUCTIONS BETWEEN THE GPS ANTENNA AND THE HORIZON:

Card 49: Initialization and Alignment Airborne Data Cards

CARD NUMBER ___

GPS/INS COUPLED INFLIGHT INITIALIZATION AND ALIGNMENT

[CALL A MARK TO THE SPACE POSITIONING GROUND STATION WHEN THE GPS IS READY.]

TIME WHEN GPS READY INDICATION PROVIDED ____________

FINAL GPS POSITION WHEN READY FOR NAV __________ __________ ALT ___

DISPLAYED TRUE COURSE ___ GROUNDSPEED ___

GROUND STATION SPACE POSITIONING ____________ ____________

GROUND STATION TRUE HEADING _________ GROUNDSPEED ________ ALT ___

TIME TO COMPLETE THE ALIGNMENT ___________

QUALITATIVE COMMENTS CONCERNING THE UTILITY OF THE ALIGNMENT STATUS AND THE ALIGNMENT COMPLETE INDICATORS:

[WHEN THE ALIGNMENT IS COMPLETE, CALL A MARK TO THE SPACE POSITIONING GROUND STATION.]

DISPLAYED INS LOCATION __________ __________ ALT ___

DISPLAYED MAGNETIC HEADING ___________

DISPLAYED TRUE HEADING__________

DISPLAYED MAGNETIC VARIATION __________

GROUND STATION SPACE POSITIONING _____________ ____________

WERE OTHER SYSTEMS/PROCEDURES WAITING ON THE INITIALIZATION OF THE GPS OR INS OR THE INS ALIGNMENT? IF SO, DESCRIBE:

Card 49: Initialization and Alignment Airborne Data Cards (Continued)

CARD NUMBER ___

GPS AIRBORNE INITIALIZATION (CORRECT POSIT AVAILABLE)

[INITIALIZE FOR A FLYOVER UPDATE.]

INITIALIZATION LOCATION __________ __________ P CODE YES/NO

INITIALIZATION HEADING __________ MAGNETIC VARIATION __________

INITIALIZATION EASE/COMPLEXITY/EFFECTS UPON OTHER PROCEDURES:

INITIALIZATION TIME __________

[WHEN THE FLYOVER UPDATE IS PERFORMED AND THUS A POSITION IS AVAILABLE TO THE GPS, START THE STOP WATCH.]

ELAPSED TIME AT START OF TIME SYNC ___________

[NOTE ANY HEADING/SPEED/ALTITUDE CHANGES WITH TIME.]

CHANGE __________ TIME________ CHANGE __________ TIME________

CHANGE __________ TIME________ CHANGE __________ TIME________

[NOTE THE ELAPSED TIME AS EACH SATELLITE IS ACQUIRED.]

SAT # __________ TIME ___________ SAT # __________ TIME ___________

SAT # __________ TIME ___________ SAT # __________ TIME ___________

SAT # __________ TIME ___________ SAT # __________ TIME ___________

Card 49: Initialization and Alignment Airborne Data Cards (Continued)

CARD NUMBER ___

GPS AIRBORNE INITIALIZATION (CORRECT POSIT AVAILABLE)

NOTE QUALITATIVE COMMENTS CONCERNING THE SATELLITE QUALITY NUMBER PROGRESSION AND UTILITY OF THE GPS READY INDICATIONS:

DESCRIBE ANY OBSTRUCTIONS BETWEEN THE GPS ANTENNA AND THE HORIZON:

[CALL A MARK TO SPACE POSITIONING GROUND STATION WHEN GPS READY.]

TIME WHEN GPS READY INDICATION PROVIDED ____________

FINAL GPS POSITION WHEN READY FOR NAV ____________ ____________

ALT _____

DISPLAYED TRUE HEADING ___

GROUNDSPEED _____

GROUND STATION SPACE POSITIONING ____________ ____________

ALT _____

GROUND STATION TRUE HEADING _____

GROUNDSPEED _____ ALT _____

NOTE IF SYSTEMS/PROCEDURES WAITING ON THE INITIALIZATION OF GPS:

Card 49: Initialization and Alignment Airborne Data Cards (Continued)

CARD NUMBER ___

GPS AIRBORNE INITIALIZATION (CORRECT POSIT NOT AVAILABLE)

[INITIALIZE FOR FLYOVER UPDATE USING INITIAL POSIT ERROR OF 300 NM]

LOCATION __________ __________ P CODE YES/NO

HEADING __________ MAGNETIC VARIATION __________

INITIALIZATION EASE/COMPLEXITY/EFFECTS UPON OTHER PROCEDURES:

INITIALIZATION TIME __________

[WHEN THE FLYOVER UPDATE IS PERFORMED AND THUS A POSITION IS AVAILABLE TO THE GPS, START THE STOP WATCH.]

ELAPSED TIME AT START OF TIME SYNC __________

[NOTE ANY HEADING/SPEED/ALTITUDE CHANGES WITH TIME.]

CHANGE __________ TIME________ CHANGE __________ TIME________

CHANGE __________ TIME________ CHANGE __________ TIME________

[NOTE THE ELAPSED TIME AS EACH SATELLITE IS ACQUIRED]

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

SAT # __________ TIME __________ SAT # __________ TIME __________

Card 49: Initialization and Alignment Airborne Data Cards (Continued)

CARD NUMBER ___

GPS AIRBORNE INITIALIZATION (CORRECT POSIT NOT AVAILABLE)

NOTE QUALITATIVE COMMENTS CONCERNING THE SATELLITE QUALITY NUMBER PROGRESSION AND UTILITY OF THE GPS READY INDICATIONS:

DESCRIBE ANY OBSTRUCTIONS BETWEEN THE GPS ANTENNA AND THE HORIZON:

[CALL A MARK TO THE SPACE POSITIONING GROUND STATION WHEN THE GPS IS READY.]

TIME WHEN GPS READY INDICATION PROVIDED ____________

FINAL GPS POSITION WHEN READY FOR NAV ____________ ____________

ALT _____

DISPLAYED TRUE HEADING ___

GROUNDSPEED _____

GROUND STATION SPACE POSITIONING ____________ ____________

ALT _____

GROUND STATION TRUE HEADING _____

GROUNDSPEED _____ ALT _____

NOTE IF SYSTEMS/PROCEDURES WAITING ON THE INITIALIZATION OF GPS:

Card 49: Initialization and Alignment Airborne Data Cards (Continued)

3.6.2. Static Position Accuracy

3.6.2.1. Purpose

The purpose of this test is to measure the static (ground position) accuracy of the coupled GPS/INS and the single GPS and INS over a mission relatable period to isolate errors that are not caused by the dynamic (flight) environment. The static accuracy becomes a baseline for measuring the effects caused by the dynamic environment.

3.6.2.2. General

In static testing, the coupled GPS/INS, GPS and INS are evaluated while the aircraft remains on the ground. Dynamic testing is performed while airborne. Static testing allows the errors caused by the INS and GPS, whether cyclic, linear, exponential, etc., to be isolated from errors induced by maneuvering effects. The static accuracy becomes the baseline from which to gauge the effects of the dynamics of flight. One mission relation for static accuracy is the requirement to perform quick reaction alerts with the system navigating statically on the ground until launch time.

3.6.2.3. Instrumentation

A stop watch and data cards are required for this test, a voice recorder is optional.

3.6.2.4. Data Required

Record the actual surveyed alignment location latitude and longitude. At five minute intervals, starting at time zero, record the elapsed time and the displayed latitude and longitude. Completely describe any aircraft motion, including the time that it occurs and note any GPS or INS fault indications.

3.6.2.5. Procedure

Complete an initialization and alignment as outlined in the previous test technique. As the INS is placed in a navigation mode, start the stop watch and record the displayed GPS and INS latitude and longitude. Record the displayed GPS and INS latitude and longitude every five minutes. Record which GPS satellites are being used, the quality number of each and finally the total GPS fix quality number at each interval. Completely describe any aircraft motion, along with the time of the occurrence. Record any GPS or INS fault indications. As a minimum, record data for the length of the maximum mission duration of the aircraft. Repeat the test with the INS turned off and then with the GPS turned off and the INS operating. Repeat the GPS tests without the GPS P code installed.

3.6.2.6. Data Analysis and Presentation

Subtract the displayed latitude and longitude from the surveyed latitude and longitude. Convert the latitude and longitude difference into nm using equation (21). Plot the data as error versus time. Annotate the plots with any significant events noted during the test, such as movement of the aircraft, system alerts and satellite switches or drops. Analyze the trend of the plots for possible causes of the errors as outlined in the theory section. Relate the static accuracy to the requirement to remain on the ground, while the INS navigates statically, for long periods of time before a quick response alert launch. Check to see if a significant change in the error plot occurs at the time of aircraft motion, when system alerts occur or after satellite changes. Relate the effects of aircraft motion to the requirement to perform maintenance on the aircraft after an alignment. Relate the static accuracy of the INS to the system alerts. If repeated alerts that imply degraded accuracy are not accompanied by that degradation, then they are false alarms. Completely investigate any INS alerts following the test. Relate the occurrence of confirmed false alarms to the possibility of unnecessarily aborted sorties.

For the case of the INS or GPS operating alone, and the case where the P code is missing, relate the drift to the requirement to perform the alert mission when the GPS user segment, control segment or space segment is not operating, when the INS is not functioning, or when the P code is lost or not available at the launch location, as appropriate.

3.6.2.7. Data Cards

A sample data card is provided as card 50.

CARD NUMBER ___

STATIC POSITION ACCURACY

[AFTER PERFORMING THE INITIALIZATION AND ALIGNMENT TEST, SELECT A NAVIGATION MODE, START THE CLOCK AND RECORD DATA AT TIME 0 AND EACH 5 MINUTES AFTER. DESCRIBE ANY SIGNIFICANT MOVEMENT OR SYSTEM ALERTS AS NOTES AT THE APPROPRIATE TIME. CONTINUE THE TEST FOR _____ MINUTES.] GPS ON ___ INS ON ___ BOTH ON ___ PCODE <u>YES/NO</u>

SURVEYED POSITION __________ __________

POINT NUMBER	ELAPSED TIME	DISPLAYED INS LAT/LONG	DISPLAYED GPS LAT/LONG	SATS/QUAL AND FIX QUAL	NOTES:

Card 50: Static Position Accuracy Data Card

3.6.3. Dynamic Non-maneuvering Position Accuracy

3.6.3.1. Purpose

The purpose of this test is to measure the dynamic, non-maneuvering position accuracy of the GPS/INS, GPS alone and INS alone and to isolate the effects of non-maneuvering flight upon the INS and GPS, and finally to qualitatively assess the utility of the INS as a navigation aid in the non-maneuvering environment.

3.6.3.2. General

Static testing provided a baseline of accuracy over time caused by errors inherent to the INS platform, accelerometers and gyroscopes and the GPS unit. Dynamic non-maneuvering position accuracy testing provides the next logical step in fully testing the INS and GPS both coupled and alone. While airborne, the aircraft is flown on navigation profiles designed to demonstrate the effects of aircraft movement during flight while minimizing any maneuvering.

For configurations where the INS is used, the profiles are flown over maximum north-south and east-west distances to excite the effects of earth rate and the Coriolis force. The flight duration should be equal to the maximum mission duration or two Schuler cycles, whichever is shorter. The optimum technique is to perform one flight on a predominately east-west profile and one on a predominately north-south profile repeating as necessary to establish the required statistical baseline. The maximum cruise range speed should be used to allow the maximum latitude and longitude to be covered.

The coupled GPS/INS is a highly accurate navigation system. This strength makes it extremely hard to test system accuracy while simultaneously navigating over long ranges, since the theodolite and laser ranger techniques described earlier are usually restricted to local testing. The long north-south and east-west legs are necessary for the coupled system since the INS dynamics described in the INS theory section can still cause system errors. Thus, it must be conceded that it is not practical to test the GPS/INS to within the expected system SEP. However, it is possible to verify that the system provides the accuracies necessary to perform the mission throughout the flight profile and to spot check the absolute accuracy at various points during the test. As part of the test to be described here, a separate, portable GPS is used to provide a relative position accuracy comparison during the long legs. This is not the optimum situation since it does not verify the absolute accuracy of the test unit, merely the accuracy relative to another GPS which can theoretically have similar errors. As a minimum, the absolute accuracy is verified at the start and at the shut down of the system. In addition, where possible, the flight profiles are planned to allow flight in the vicinity of a facility capable of providing the highly accurate theodolite or laser tracker space positioning data.

When the GPS is running alone, the system errors are not driven by the INS dynamics and the need to cover rigid flight profiles is lessened, allowing the system to be flown in the vicinity of a space positioning facility. The GPS position is thus compared to the accurate space positioning data at frequent times during the flight. For the case where the INS is run alone, the test is conducted identically to the dynamic non-maneuvering test described previously in the INS testing section. Since the expected accuracy of the INS system alone is much less than the coupled system or the GPS system alone, the flyover method is adequate.

3.6.3.3. Instrumentation

A portable GPS receiver, stop watch and data cards are required for this test, a voice recorder is optional. A properly instrumented range including highly accurate laser ranger or theodolite tracking is required. For the case where a laser ranger is used, a laser reflector array must be installed on the test aircraft.

3.6.3.4. Data Required

For the configuration where the GPS and INS are available and coupled, after recording the initialization and alignment data, record the displayed latitude and longitude as a navigation mode is selected. Record the GPS/INS and portable GPS latitude and longitude; the satellites used, their quality numbers and the total fix quality number; also record the GPS/INS and portable GPS altitude, course and groundspeed, all at five-minute intervals. At each laser ranger or theodolite flyover point, record the elapsed time, point identification, altitude, GPS/INS displayed latitude and longitude, satellites used, satellite quality numbers, total fix quality number, altitude, course, groundspeed and laser or theodolite calculated latitude and longitude, altitude, course and groundspeed. After the taxi back to the hangar, record the surveyed parking location, elapsed time and GPS/INS displayed latitude and longitude. Throughout the flight, record as notes on the data cards, any maneuvers requiring over 1.5 g, 30° angle of bank, or 20° of pitch, any airspeed changes of over 50 KIAS (other than takeoff and landing) and any INS or GPS system alerts, along with the elapsed time of occurrence. Record qualitative comments concerning the utility of the GPS/INS in navigating to each waypoint along the route.

Record the same data for the GPS-alone test condition, deleting the INS alerts. Repeat both tests with the P code not installed. When using the INS alone, record the data described in the INS test procedures presented earlier.

3.6.3.5. Procedure

For the case of the coupled GPS/INS, prior to the test flight, plan a route that provides a flyover of as many accurate space positioning ranges as possible. Plan at least one flight predominately east-west and one north-south. Choose a flight profile consistent with normal, long range cruise.

Perform an Initialization and Alignment test as previously outlined. When the alignment is complete, select a navigation mode, start the stop watch and then record the displayed latitude and longitude. At five-minute intervals, record the elapsed time along with the GPS/INS and portable GPS positions, satellites used and the quality numbers described in the data section. Record any system alerts with the elapsed time as notes.

Perform a normal airfield departure, navigating to the initial waypoint. Select an airspeed near the maximum range airspeed at the test altitude and set this airspeed as early as possible. Attempt to maintain this airspeed throughout as much of the flight as possible. Care must be taken to limit maneuvering. Keep g, pitch and bank to a minimum, recording the elapsed time and a complete description of all deviations. Generally, anything over 1.5g, 30° angle of bank, 20° of pitch or 50 KIAS of airspeed change should be noted.

While navigating to the waypoints, evaluate the utility of the GPS/INS displays/controls, utility of the GPS/INS derived steering cues, as well as the integration of the navigation information within the aircraft as a navigation aid in the non-maneuvering environment.

When flying over the precise space positioning sources, record the same data required for the five-minute data points in addition to the theodolite or laser ranger derived positioning data.

Following touchdown and rollout, taxi to a surveyed parking area. Before shutdown, record the elapsed time and displayed latitude and longitude.

Repeat the test for the case where the GPS is used alone. The entire flight may be performed in the vicinity of a space positioning range. Repeated laser ranger or theodolite fixes at 5 to 15-minute intervals are required. Repeat the first two tests without the P code installed.

For the condition where the INS is used alone, perform the test as outlined in the INS test procedure section.

3.6.3.6. Data Analysis and Presentation

Subtract the coupled GPS/INS displayed latitude and longitude from the surveyed point latitude and longitude or precise space positioning derived latitude and longitude, as appropriate. Convert the latitude and longitude difference to nm using equation (21). Plot the data as latitude and longitude error versus elapsed time. Annotate the plots with any significant events noted during the test, such as system alerts or maneuvering above 1.5g, 30° angle of bank, 20° of pitch or airspeed changes of 50 KIAS. Apply the same procedure to the GPS/INS and the portable GPS-derived positions and add to the same plot using different symbols.

Develop similar plots comparing the GPS/INS altitude, course and groundspeed and the data collected from the space positioning data and the hand-held GPS.

Analyze the trend of the plots for the possible causes of the errors. If the start-up and shut-down surveyed points and the precise space positioning data points show little error for the portable GPS, assume that the portable GPS may be used as a truth data source for the times between the absolute fixes. Typically, the GPS will provide such precise updates at such frequent intervals that the INS errors discussed in the INS section will not be evident.

Since the time dependent errors of the INS are not easily seen in the coupled system, it is also useful to develop a scatterplot as defined in the OMEGA section to highlight any errors caused by the position fixing GPS receiver.

Relate the non-maneuvering accuracy of the coupled GPS/INS to the requirement to perform non-maneuvering navigation during ferry missions and while ingressing from the base airfield to enemy lines.

If excessive maneuvers are recorded during the flight, check for significant changes in the error curves following the maneuver time. Relate excessive changes in the drift rate to the requirement to perform evasive maneuvers inbound to a target while still requiring accurate navigation information for the return to the home airfield. If system alerts are noted during the flight, check for significant changes in the error rate curve following the time the alert is noted. Thoroughly investigate any INS alerts after the flight. Alerts that imply degraded accuracy and do not result in a change on the error curve or cannot be associated with a system failure should be related to the possibility of unnecessarily aborted sorties (false alarms). Relate the utility of the GPS/INS displays/controls, steering cues and integration within the aircraft to the usefulness of the INS as an aid for navigating to waypoints, the target position and later returning to the home airfield.

Analyze the recorded satellites and quality numbers for changes and drops, checking for corresponding degradation in the navigation accuracy. If the accuracy is degraded beyond the necessary accuracy, follow up with an investigation of the satellite geometry and the appropriateness of the individual satellite selections.

Repeat the procedure for the case of the GPS alone. The time base plot is not normally used for a position fixing system, however it may be useful to highlight the effects of satellite swaps and drop outs and of any maneuvers performed. Relate the performance to the necessity to perform the mission after the INS has failed or after an alert launch that did not allow for the alignment of the INS.

Analyze the data derived with the P code missing in the same fashion as the two previous sets of data. Relate the data to the necessity to perform the mission after the P code is dropped or when it is not available due to operational constraints.

Reduce and analyze the INS alone data identically to the process outlined in the INS test procedures.

3.3.3.7. Data Cards

A sample data card is provided as card 51.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

DYNAMIC NON-MANEUVERING POSITION ACCURACY

[AFTER PERFORMING THE INITIALIZATION AND ALIGNMENT TEST, SELECT A NAVIGATION MODE, START THE STOP WATCH AND RECORD THE LATITUDE AND LONGITUDE AND SATELLITE DATA. AFTER TAKEOFF, SET ___KIAS, CLIMB TO ____ FEET MSL AND BEGIN NORMAL EN ROUTE NAVIGATION. RECORD THE GPS/INS AND PORTABLE GPS DATA AT FIVE MINUTE INTERVALS. RECORD AS NOTES SYSTEM ALERTS AND MANEUVERS ABOVE 1.5G, 30° ANGLE OF BANK, 20° OF PITCH OR 50 KIAS OF AIRSPEED CHANGE WITH TIME AS REQUIRED. RECORD QUALITATIVE COMMENTS CONCERNING UTILITY FOR NON-MANEUVERING FLIGHT OF NAVIGATION DISPLAYS, STEERING CUES AND NAVIGATION ACCURACY. RECORD DATA BEFORE SHUTDOWN.]

SURVEYED ALIGNMENT LOCATION __________ __________

DISPLAYED WHEN SELECTED _________ __________

CONFIGURATION: GPS ON ___ INS ON ___ BOTH ON ___

P CODE: YES / NO

SATELLITES IN USE/QUALITY NUMBERS:

TOTAL FIX QUALITY NUMBER ______

NOTES:

Card 51: Dynamic Non-maneuvering Position Accuracy Data Cards

CARD NUMBER ___

DYNAMIC NON-MANEUVERING POSITION ACCURACY

TIME	HAND-HELD GPS POSITION/SPACE POSIT FIX IF APPLICABLE/ALT/ COURSE/GROUND-SPEED	GPS/INS POSITION /ALT /COURSE/ GROUND-SPEED	SATELLITES/ QUALITY NUMBERS	TOTAL FIX QUALITY NUMBER	NOTES:

Card 51: Dynamic Non-maneuvering Position Accuracy Data Cards (Continued)

CARD NUMBER ___

DYNAMIC NON-MANEUVERING POSITION ACCURACY

SURVEYED SHUTDOWN LOCATION __________ __________

ELAPSED TIME AT SHUT DOWN _____

DISPLAYED AT SHUTDOWN __________ __________

QUALITATIVE COMMENTS CONCERNING UTILITY DURING NON-MANEUVERING FLIGHT OF NAVIGATION DISPLAYS/CONTROLS:

GPS/INS OR GPS ALONE STEERING CUES:

NON-MANEUVERING ACCURACY:

Card 51: Dynamic Non-maneuvering Position Accuracy Data Cards (Continued)

3.6.4. Dynamic Maneuvering Position Accuracy

3.6.4.1. Purpose

The purpose of this test is to measure the dynamic maneuvering position accuracy of the GPS/INS, GPS alone and INS alone to isolate the effects of various types of aircraft maneuvers and to qualitatively assess the utility of the system as a navigation aid in the maneuvering environment.

3.6.4.2. General

Dynamic non-maneuvering position accuracy testing provided a baseline of accuracy which included the effects of strictly non-maneuvering flight. Using this baseline data, the aircraft will perform a series of maneuvers with space positioning data taken after each maneuver. The exact flight profile will have little effect upon the accuracy compared to the effects of maneuvering. For this reason, a single, laser tracker or theodolite array can be repeatedly used. A significant departure from the dynamic baseline data plot will be due to aircraft maneuvering. In this way, the effects of mission relatable maneuvering upon system accuracy will be isolated from other effects. Low acceleration roll, pitch (a loop maneuver will be used) and yaw maneuvers will be used to check for INS gimbal limits as well as attitudes where GPS coverage is significantly degraded. Airspeed limitations will be checked while accelerating from a slow airspeed to the airspeed limit of the aircraft. Roll, pitch, yaw and level turn maneuvers to the limits of the aircraft will be used to assess the effects of maneuvers in a single plane. Finally, rolling push-overs and pull-ups will be performed to the aircraft limits to check the effects of multi-axis maneuvers. Table VI shows the typical linear and angular dynamic limits for a notional GPS unit designed for use on a tactical platform [Ref. 10].

3.6.4.3. Instrumentation

A stop watch and data cards are required for this test, a voice recorder is optional. A properly instrumented range including highly accurate laser ranger or theodolite tracking is required. For the case where a laser ranger is used, a laser reflector array must be installed on the test aircraft.

3.6.4.4. Data Required

For the configuration where the GPS and INS are available and coupled, after

Table VI: Typical GPS Linear and Angular Dynamic Limits

	Linear Dynamics[1]	Angular Dynamics
Velocity (m/sec) or Rate (rad/sec)[2]	1,200	yaw ± 1.0
		pitch ± 1.0
		roll ± 5.5
Acceleration (m/sec^2 or rad/sec^2)[2]	90	yaw ± 3.0
		pitch ± 6.0
		roll ± 17.5
jerk (m/sec)	100	not usually specified

(1) Any linear axis.
(2) As appropriate.

recording the initialization and alignment data, record the displayed latitude and longitude as a navigation mode is selected. At each laser ranger or theodolite flyover point, record the elapsed time, altitude, GPS/INS displayed latitude and longitude, satellites used, satellite quality numbers, total fix quality number and laser or theodolite calculated latitude and longitude. After the taxi back to the hangar, record the surveyed parking location, elapsed time and GPS/INS displayed latitude and longitude. Throughout the flight, record as notes on the data cards, any INS or GPS system alerts, along with the elapsed time of occurrence. Record qualitative comments concerning the utility of the GPS/INS in navigating to and from the test area as well as during the maneuvers.

Record the same data for the GPS-alone test condition, deleting the INS alerts. Repeat both tests without the P code installed. When using the INS alone, record the data described in the INS test procedures provided earlier.

3.6.4.5. Procedure

During preflight planning, choose a point within range of a laser tracker or within the operating area of a theodolite array that allows low and medium altitude maneuvering as well as supersonic flight at low and medium altitudes in the case of a supersonic test aircraft. Choose an initial airspeed that conserves fuel. Record GPS/INS and space positioning data upon arriving within the test area as described in the dynamic non-maneuvering position accuracy section. Climb to a moderately low altitude in the case of an attack aircraft and a medium altitude in the case of a fighter aircraft and perform a maximum power acceleration to the limit airspeed or mach number of the aircraft. A shallow dive can be used to expedite the maneuver as long as it can be safely performed at the chosen altitude. When a dive is used, an initial altitude above the test altitude should be chosen. Generally, the rate of descent should never exceed 1/2 of the aircraft altitude for safety purposes.

Following the acceleration, decelerate to a good maneuvering speed while performing a 1.5 g or less turn, return to the range area and again record GPS/INS and space positioning data. Next, climb to a medium low altitude and perform a constant 3 g, 360° turn. Use the best maneuvering airspeed, or the cornering airspeed, for the test. The cornering airspeed will be available from the aircraft operating manual. Return to the range area and again collect the GPS/INS and space positioning data. Repeat at 5 g and then at the maximum aircraft level g. For the fighter aircraft test, perform the maximum g test at a medium altitude. Next, climb to a medium low altitude, set a good maneuvering airspeed and perform an aileron roll at 1/4 stick deflection. Again collect the GPS/INS and space positioning data. Repeat at 1/2 stick deflection and then at full stick deflection or at the aircraft roll limit, whichever is greater. Again at a medium low altitude provide a step rudder input at 1/4 and 1/2 rudder deflection and finally at either full rudder deflection or the aircraft rudder input limit. Collect the same data between each input.

Finally, climb to a medium low altitude and perform a series of rolling push-overs and pull-ups, increasing the g to the aircraft limits. After reaching the aircraft limit, collect the same data. Return to the home airfield. Before shut down, record the shut-down spot surveyed latitude and longitude, the elapsed time and the displayed latitude and longitude. During the entire flight, watch for GPS and INS system discretes and record them as notes along with the time of occurrence. Thoroughly investigate all failure discretes after the flight. In addition, qualitatively evaluate the INS controls, steering cues, displays and accuracy as an aid for finding the flyover points in the maneuvering environment.

Repeat the test for the case where the GPS alone is used. The entire flight may be performed in the vicinity of a space positioning range. Repeated laser ranger or theodolite fixes at 5 to 15-minute intervals are required. Repeat the first two tests without the P code installed.

For the condition where the INS is used alone, perform the test as outlined in the INS test procedure section.

3.6.4.6. Data Analysis and Presentation

Subtract the coupled GPS/INS displayed latitude and longitude from the surveyed point latitude and longitude or precise space positioning derived latitude and longitude, as appropriate. Convert the latitude and longitude difference to nm using equation (21). Plot the data as latitude and longitude error versus elapsed time. Annotate the plots with all the maneuvers performed before each point was recorded as well as any system alerts or changes in the GPS satellites in use. Check the plot for any significant change in the slope of the error plot and relate any changes to the effect these maneuvers have upon GPS/INS accuracy. Further relate the error to the loss of accuracy during mission relatable ACM for fighters and evasive maneuvering inbound to the target for attack aircraft.

Since the time dependent errors of the INS are not easily seen in the coupled system, it is also useful to develop a scatterplot as defined in the OMEGA section to highlight any errors caused by the position fixing GPS receiver.

If system alerts are noted during the flight, check for significant changes in the error rate curve following the time the alert is noted. Thoroughly investigate any GPS or INS alerts after the flight. Alerts that imply degraded accuracy and do not result in a change on the error curve or cannot be associated with a system failure should be related to the possibility of unnecessarily aborted sorties (false alarms). Relate the utility of the GPS/INS displays/controls, steering cues and integration within the aircraft to the usefulness of the INS as an aid for navigating to waypoints, the target position and later returning to the home airfield.

Analyze the recorded satellites and quality numbers for changes and drops, checking for corresponding degradation in the navigation accuracy. If the accuracy is degraded beyond the necessary accuracy, follow up with an investigation of the satellite geometry and the appropriateness of the individual satellite selection.

Repeat the procedure for the case of the GPS alone. The time base plot is not normally used for a position fixing system, however it may be useful to highlight the effects of satellite swaps and drop outs and of the individual maneuvers. Relate the performance to the necessity to perform the mission after the INS has failed or after an alert launch that did not allow for the alignment of the INS.

Analyze the data derived with the P code missing in the same fashion as the two previous sets of data. Relate the data to the necessity to perform the mission after the P code is dropped or when it is not available due to operational constraints.

Reduce and analyze the INS-alone data identically to the processes outlined in the INS test procedures.

3.6.4.7. Data Cards

Sample data cards are provided as card 52.

CARD NUMBER ___ TIME ___ PRIORITY L/M/H

DYNAMIC MANEUVERING POSITION ACCURACY

[AFTER PERFORMING THE INITIALIZATION AND ALIGNMENT TEST, SELECT A NAVIGATION MODE. START THE STOP WATCH AND RECORD THE LATITUDE AND LONGITUDE. AFTER TAKEOFF, SET ___ KIAS, CLIMB TO _____ FEET MSL AND ASSUME NAVIGATION TO THE RANGE TAKING DATA ONCE THERE. PERFORM EACH MANEUVER AND BETWEEN EACH TAKE A DATA POINT. RECORD AS NOTES SYSTEM ALERTS AS WELL AS GPS SATELLITE CHANGES. RECORD QUALITATIVE COMMENTS CONCERNING SYSTEM UTILITY FOR NAVIGATION DURING MANEUVERING FLIGHT OF DISPLAYS/CONTROLS, STEERING CUES AND NAVIGATION ACCURACY. RECORD DATA BEFORE SHUTDOWN.]

SURVEYED ALIGNMENT LOCATION __________ __________

DISPLAYED WHEN SELECTED __________ __________

CONFIGURATION: GPS ON ___ INS ON ___ BOTH ON ___

P CODE: YES / NO

SATELLITES IN USE/QUALITY NUMBERS:

TOTAL FIX QUALITY NUMBER ______

NOTES:

Card 52: Dynamic Maneuvering Position Accuracy Data Cards

CARD NUMBER _____

DYNAMIC MANEUVERING POSITION ACCURACY

TRANSIT AIRSPEED ___ KIAS

TRANSIT ALTITUDE _____ FEET MSL

OPTIMUM LOCATION FOR COLLECTING POSITIONING DATA _________ _________

MAN-EUVER	ALT/AIR-SPEED (FT MSL /KIAS)	TIME/ FLY-OVER ALT (FT MSL)	DISPLAYED/ RANGE DERIVED POSITION AND ALT (FT)	SATELLITE/ QUALITY NUMBERS	TOTAL FIX QUAL NUM-BER	NOTES:
INITIAL FLYOVER						
MAX LEVEL ACCEL						
LEVEL TURN 3G						
LEVEL TURN 5G						
LEVEL TURN _G						

Card 52: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

DYNAMIC MANEUVERING POSITION ACCURACY

MAN-EUVER	ALT/AIR-SPEED (FT MSL /KIAS)	TIME/ FLY-OVER ALT (FT MSL)	DISPLAYED/ RANGE DERIVED POSITION AND ALT (FT)	SATELLITE/ QUALITY NUMBERS	TOTAL FIX QUAL NUM-BER	NOTES:
1/4 STICK ROLL						
1/2 STICK ROLL						
FULL STICK ROLL						
1/4 RUDDER						
1/2 RUDDER						
FULL RUDDER						

Card 52: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

CARD NUMBER _____

DYNAMIC MANEUVERING POSITION ACCURACY

MAN-EUVER	ALT/AIR-SPEED (FT MSL /KIAS)	TIME/ FLY-OVER ALT (FT MSL)	DISPLAYED/ RANGE DERIVED POSITION AND ALT (FT)	SATELLITE/ QUALITY NUMBERS	TOTAL FIX QUAL NUM-BER	NOTES:
ROLLING PUSH-OVERS/ PULL-UPS						

SURVEYED SHUTDOWN LOCATION __________ __________

ELAPSED TIME AT SHUT DOWN _____

DISPLAYED AT SHUTDOWN __________ __________

QUALITATIVE COMMENTS CONCERNING UTILITY DURING MANEUVERING FLIGHT OF NAVIGATION DISPLAYS/CONTROLS:

GPS/INS STEERING CUES:

MANEUVERING ACCURACY:

Card 52: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

3.6.5. Navigation Performance in Overwater/Multipath Environment

3.6.5.1 Purpose

The purpose of this test is to assess the effects of satellite signal multipath upon the GPS system accuracy and utility.

3.6.5.2. General

The GPS satellite signal tends to reflect off of the surface of bodies of water. Typically, the smoother the surface, the better the surface will reflect. When an aircraft flies at low altitudes along the surface of the water, the aircraft will receive two signals from the GPS satellite, one sent directly from the satellite and the second sent from the satellite and then reflected off the surface of the water and thence directly to the aircraft. The reflected signal can interfere with the direct signal, causing the satellite quality numbers to become degraded and subsequently the total fix quality number also becomes degraded. The problem will vary with aircraft altitude above the surface; however, the effect will not normally be seen above 500 to 1,000 feet AGL. The multipath problem will also vary with the roughness of the water surface. The worst case will occur when the surface is smooth.

3.6.5.3. Instrumentation

A stop watch and data cards are required for this test, a voice recorder is optional. A properly instrumented range including highly accurate laser ranger or theodolite tracking is required. For the case where a laser ranger is used, a laser reflector array must be installed on the test aircraft.

3.6.5.4. Data Required

At altitude, note the satellites in use, satellite quality numbers and total fix quality number. Record the time, GPS-derived latitude and longitude and laser ranger or theodolite-derived latitude and longitude. After descending, note any times where the individual satellite quality numbers degrade. If low altitude fixes are required, record the elapsed time, altitude, GPS/INS displayed latitude and longitude, satellites used, satellite quality numbers, total fix quality number and laser or theodolite calculated latitude and longitude.

3.6.4.5. Procedure

Perform the test when the surface of the water in the vicinity of a space positioning range is as smooth as possible. This provides a worst case situation for satellite signal multipath. Begin the test at an altitude of at least 5,000 feet AGL with the GPS running alone. While minimizing maneuvers, note the satellite data, GPS position data and space positioning data.

Descend to the minimum altitude allowable considering the aircraft and qualifications of the test pilot. Usually 100 to 200 feet is sufficient. If possible, crew duties should be split to allow one person to fly the aircraft while the other collects data. Again, note the satellite data and compare to the previous satellites used and quality numbers. If the quality of the satellite signals are reduced notably, repeat the GPS position and space positioning data point. Repeat the low level portion of the test at 60° heading intervals. If multipath was noted with the P code installed, repeat the test with the P code not installed.

3.6.4.6. Data Analysis and Presentation

If the quality numbers are not degraded at low altitude, assume that the multipath effects are not present. If significant differences were noted, the additional space positioning data must be evaluated to determine the correlation between the degraded quality numbers and the actual degradation in positioning accuracy. For the data collected at the higher altitude, subtract the coupled GPS displayed latitude and longitude from the precise space positioning derived latitude and longitude. Convert the latitude and longitude difference to nm using equation (21). Repeat the procedure for the low level data at all headings where degradation was noted. Relate the degree of degradation to the necessity to perform low level navigation using GPS-derived data during attacks on shipping or during ingress and egress over the coastline.

3.6.4.7. Data Cards

Sample data cards are provided as card 53.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

PERFORMANCE IN OVERWATER/MULTIPATH ENVIRONMENT

[USE GPS ALONE WITH INS SET TO OFF. CLIMB TO ___ FT AGL AND SET ___ KIAS. MINIMIZE MANEUVERING. NOTE SATELLITE DATA.]

P CODE: YES / NO

SATELLITES IN USE/QUALITY NUMBERS:

TOTAL POSITION QUALITY NUMBER ______

TIME _____ SPACE POSIT LAT/LONG __________ / __________

NOTES:

Card 53: Navigation Performance in Overwater/Multipath Environment

CARD NUMBER ___

PERFORMANCE IN OVERWATER/MULTIPATH ENVIRONMENT

[DESCEND TO ___ FT AGL AND SET ___ KIAS. MAINTAIN HEADING AND NOTE SATELLITE QUALITY NUMBERS AND IF DEGRADED. IF DEGRADED, NOTE REST OF DATA LISTED ON CARD.]

TIME	GPS LAT /LONG	SATELLITES/QUAL NUM	TOTAL QUAL NUM	HEADING	ALT	SPACE POSIT LAT/ LONG

Card 53: Navigation Performance in Overwater/Multipath Environment (Continued)

3.6.6. Mission Utility and Integration

3.6.6.1. Purpose

The purpose of this test is to qualitatively assess the integration of the GPS and the INS with the other aircraft navigation systems, the utility of the GPS and INS with the other aircraft avionics systems and sensors and the integration of the GPS and INS displays and controls as an aid for navigation and locating targets in a mission relatable environment.

3.6.6.2. General

In most cases, the GPS and INS are not stand-alone systems. Many modern avionics systems require navigation inputs. Radar and Forward Looking Infrared Radar (FLIR) displays and antennas are often geographically stabilized using INS and/or GPS inputs. The INS can use sensor and other navigation system inputs for position updates. Navigation information is often displayed on radar and FLIR displays, tactical displays and HUDs. A typical system will use radar input to the navigation system which provides initial steering to the target (the navigation system also is stabilizing the radar scan center to maintain detection of the target). The navigation input is then used to steer the FLIR onto the target for a FLIR handoff. The navigation cues are provided on the HUD, often including a navigation system stabilized target designator box, to aid in visually finding the target. If detection is lost, such as during the terminal phase of a DBS radar attack, the navigation system provides final attack cues. Finally, during the weapons release, the navigation system provides inputs to the weapons computer to calculate the proper release point, again providing cues to the pilot.

In most cases, the navigation system requires the widest integration within the complete aircraft of any system and as such is the most challenging to test for integration. Since the output of the INS (latitude and longitude) and of the GPS (latitude, longitude and time) is rarely used directly by the pilot, the issues of integration and accuracy nearly completely define the utility of the INS.

The utility and integration of the navigation system can only be evaluated during mission relatable tasks. For an attack aircraft, the evaluation must be performed during mission relatable ingresses to the target area, detection of the target, handoff between the sensors as would be expected in a tactically significant attack, (for example a handoff from a long range radar detection to a FLIR attack) selection of a weapon and attack mode, and finally, a safe egress from the target area. For a fighter, the evaluation requires navigating to and from a Combat Air Patrol (CAP) station, steering cues to a radar designated target, handoff to an air-to-air FLIR or other electro-optic sensor for VID as well as navigation inputs to digital data links and tactical displays. The critical requirement is to select a scenario that reflects the most likely use of the aircraft and to use this scenario during the evaluation. For the purpose of this sample test procedure, the test aircraft will be an attack aircraft with a weapons computer, HUD, radar and FLIR, as well as the TACAN and OMEGA systems used to demonstrate the previous tests.

3.6.6.3. Instrumentation

Data cards are required for this test. A voice recorder is highly recommended.

3.6.6.4. Data Required

Record qualitative comments concerning the integration of the GPS/INS system with the aircraft weapons computer, FLIR, HUD, radar and TACAN. Include comments concerning the INS and GPS inputs to these systems as well as the radar and TACAN inputs to the INS for INS updates during tests where the GPS is not used. Evaluate the effects of GPS and INS accuracy upon other systems, for instance the drift rate of radar and FLIR geographically stabilized cursors, once a target is selected, and the resulting workload as the cursors are repeatedly updated. Evaluate the effects of navigation functions, such as INS update procedures, upon operator workload during a mission relatable environment. Assess the utility of the GPS and INS-derived information displayed upon the radar, FLIR, HUD, as well as GPS and INS unique displays including the effects of GPS and INS accuracy, while performing radar to FLIR or HUD handoffs and mission-relatable ingresses, attacks and egresses.

3.6.6.5. Procedure

Select a mission-relatable target in the test area that allows for a 35 to 40 nm ingress to the target location. Select several waypoints inbound to the target. While navigating from the home airfield to the initial waypoint, qualitatively assess the utility of the GPS/INS accuracy and steering cues for long range, IMC navigation. Choose an altitude and airspeed that conserves fuel. Descend to a low ingress altitude and set an airspeed near the sea level limit of the test aircraft. Head inbound to the target and select a radar mapping mode with at least a 40 nm scale and a wide scan pattern useful for radar mapping. Follow the navigation system and radar cues inbound to the target, passing over the waypoints along the route. Select DBS radar modes inbound to the target; and when inside of 10 nm perform a handoff of the target from the radar to the FLIR. Continue inbound to the target, performing a mission-relatable, unguided, ordnance attack on the target. Following the attack, turn outbound from the target and navigate to the initial point on the reverse route using the radar and navigation system cues. Repeat with different weapons deliveries as time allows. Use a voice recorder or write down comments after each run. Care should be taken not to become distracted with recording data to allow the best overall qualitative evaluation. Repeat the test with the INS turned off and then using the INS alone. Finally, repeat the GPS test without the P code installed.

3.6.6.6. Data Analysis and Presentation

Relate the qualitative deficiencies noted to their effects upon the performance of normal IFR navigation, ingresses and attacks. Note any limitations upon tactics imposed by the system accuracy, utility or integration. For instance, the navigation cues used to find the waypoints may require so much operator attention and interpretation that they destroy the scan of the radar display while searching for the target. As another example, the navigation drift may be so high that the stored position of the target may drift radically between the last radar or FLIR update and the weapons release, causing a miss of the target. It is critical that the navigation system utility and integration should not be driving tactics. Use the applicable results from the previous tests to support the qualitative results. Relate the same factors for the INS and GPS-alone configurations to the requirement to perform the mission following a system failure or after having to launch without a complete INS alignment. Relate the configurations where the P code is not installed to the requirement to perform the mission after the P code is lost or when operating out of a base where the P code is not available.

3.6.6.7. Data Cards

A sample data card is presented as card 54.

CARD NUMBER ___ TIME___ PRIORITY L/M/H

GPS/INS MISSION UTILITY AND INTEGRATION

CONFIGURATION: GPS ON ___ INS ON ___ BOTH ON ___ P CODE YES/NO

[AFTER TAKEOFF, CLIMB TO _____ FEET MSL AND SET ___ KIAS. PERFORM NAVIGATION TO THE INITIAL POINT, ASSESSING THE UTILITY OF NAVIGATION SYSTEM ACCURACY AND DISPLAYS FOR IMC NAVIGATION. DESCEND TO ___ FEET AGL AND ___ KIAS AT THE INITIAL WAYPOINT. SET A 40 NM RADAR SCALE AND __° SCAN ANGLE LIMIT. SEARCH FOR THE TARGET ON THE RADAR WHILE NAVIGATING TO THE WAYPOINTS. AT 10 NM, PERFORM A FLIR HANDOFF. PERFORM A __________ ATTACK. AFTER RELEASE, REVERSE THE INGRESS TRACK. REPEAT USING A __________, __________ AND __________ ATTACK AS FUEL ALLOWS.]

TARGET POSITION __________ __________

INITIAL WAYPOINT 1 POSITION __________ __________

WAYPOINT 2 POSITION __________ __________

WAYPOINT 3 POSITION __________ __________

NOTES:

Card 54: GPS/INS Mission Utility and Integration Data Card

3.6.7. Introduction to Advanced Coupled Global Positioning System/Inertial Navigation System Test Techniques

As mentioned in Chapter 1, only the most rudimentary form of the coupled global positioning system/inertial navigation system test techniques are presented in this book. Chapter 1 details the reasons for this format; however, in many applications, more rigor, accuracy and documentation of results are required. Table VI outlines additional instrumentation and assets which are typically applied in these more advanced tests. The purpose of this table is merely to emphasize the existence of these advanced techniques. Further, this list is not exhaustive. Many innovative uses of assets and instrumentation exist. It is hoped that the examples provided leave the reader with a taste of how the test can be made more rigorous through the judicious use of instrumentation. In application; the user must refer to the more advanced documents referenced in Chapter 1 or solicit help from more experienced testers.

Table VI: Additional Assets or Instrumentation for use in Advanced Coupled Global Positioning System/Inertial Navigation System Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Initialization and Alignment.	Digital recording of navigation data bus to include all Inertial Navigation System (INS) and Global Positioning System (GPS) outputs, GPS initialization and INS alignment parameters and operator actions and inputs. Precisely surveyed alignment location and boresighted aircraft heading and orientation.	Entire initialization and alignment process is captured allowing isolation of poor alignment performance. Initialization process is recorded and correlated to operator selections. Final initialization and alignment results are compared to known alignment location and aircraft orientation.
Static Position Accuracy.	Digital recording of INS and GPS derived position and rates as well as GPS satellite selections. Calibrated, ground based GPS receiver. Video recording of display. Precisely surveyed alignment location.	Digital position and rates are compared to the known static values. Satellite selections and position calculated by calibrated, ground based GPS receiver are examined if GPS accuracy is a problem. Display output to the operator is compared to the direct INS output.

 Table VI: Additional Assets or Instrumentation for use in Advanced Coupled Global Positioning System/Inertial Navigation System Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Dynamic Non-maneuvering Position Accuracy.	Digital recording of time stamped aircraft rates and precise space positioning data, INS and test GPS derived time stamped position and rates, GPS satellite selections, system modes and operator actions. In some cases, particularly when the filter algorithms are in development, the inputs to the filter are digitally recorded. Video recording of the display.	The profile is flown without the necessity of surveyed point flyovers. Space positioning data and aircraft rates are continuously recorded and later compared to INS and GPS derived values. If derived from a range, the profile is often constrained geographically. A second GPS, of known performance, can sometimes be used with sufficient accuracy to avoid constricting the profile. Recorded aircraft dynamics are also examined to correlate maneuvering excursions with changes in INS and coupled GPS/INS drift rates. When the GPS accuracy is degraded, the satellite selections are examined for anomalies. System modes (for instance when the system degrades to an INS only mode when satellite tracking is lost) are verified for their appropriateness. The inputs to the GPS/INS filter are sometimes needed to develop and verify the filter weights. The display video is compared to the INS/GPS bus data to check for inconsistencies caused by the manipulation of the INS data and then its display.
Dynamic Maneuvering Position Accuracy.	As for the Dynamic Non-maneuvering Position Accuracy test.	Typically, precise space positioning data is derived from an instrumented range. Aircraft dynamics can be derived from either on or off the aircraft. The INS/GPS derived rates and position are compared directly with the time correlated data as the maneuvers are performed. When the GPS accuracy is degraded, the satellite selections are examined for anomalies. System modes (for instance when the system degrades to an INS only mode when satellite tracking is lost) are verified for their appropriateness. The inputs to the GPS/INS filter are sometimes needed to develop and verify the filter weights. The display video is compared to the INS/GPS bus data to check for inconsistencies caused by the manipulation of the INS data and then its display.

Table VI: Additional Assets or Instrumentation for use in Advanced Coupled Global Positioning System/Inertial Navigation System Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Navigation Performance in Overwater /Multipath Environment	Digital recording of the data derived from each receiver channel if possible.	If possible, the output of each receiver channel is recorded and compared to a calibrated, ground based GPS of known characteristics to check for the presence of multipath phenomenon. This is often not practical due to system architecture and multipath is inferred by recording the parameters listed for the Dynamic Maneuvering Position Accuracy test. The data is then analyzed for the multipath induced, characteristic loss of accuracy and variances in satellite quality while flying the aircraft to induce the multipath phenomenon.
Mission Utility and Integration.	As for the Dynamic Non-maneuvering Position Accuracy as well as the Navigation Performance in Overwater/Multipath Environment tests.	This test requires the largest amount of data to completely document the results. It is during this test that most of the unexpected problems are found. In anticipation of having to document these deficiencies, maximum instrumentation and range support are sometimes brought to bear in case unforseen data are required in post-flight analysis.

4.0. ELECTRO-OPTICAL SYSTEM TESTING

4.1. Introduction to Electro-Optical Theory

4.1.1. General

Figure 12 depicts the electromagnetic spectrum [Ref. 37:pp. 2.1a,2.82a]. The portion of the spectrum applicable to Electro-Optical (EO) systems lies between the Extremely High Frequency (EHF) band and the X-ray band [Ref. 37:p. 2.1]. EO systems are very similar in concept to their RF band counterparts including the radars discussed earlier; however, they have some unique strengths and weaknesses. Due to their extremely high frequencies and small wavelengths, the bandwidths of EO sensors are extremely high, and very narrow beamwidths are possible, providing highly accurate systems, capable of imaging. Narrow beam widths make EO systems hard to jam. [Ref. 37:p. 1.1].

Common applications of EO systems include [Ref. 37:p. 1.1] (Note that there is an RF counterpart to each application):

Threat Detection, Identification and Tracking
Threat Detection and Warning
Surveillance and Ground Mapping
Navigation
Communications
Weapons Delivery
Direct Radiation Weapons

For the purposes of demonstrating the thought process used for developing EO test techniques, this book will concentrate on passive systems, since these systems are perhaps the most unique of the EO category of avionics.

4.1.2.Infrared Systems

A large majority of EO systems operate in the near, middle and far InfraRed (IR) band. Additionally, the test techniques used to test IR systems are similar to the techniques used to test all EO systems. For these reasons, a sample IR system will be used to demonstrate the procedure used to develop all EO test techniques. The generalized thought process may then be applied to develop tests for specific systems.

All objects above a temperature of absolute zero emit within the IR bandwidth. The amount and frequency of the IR radiation emitted varies with the temperature of the object [Ref. 74:Chap. 3]. When operating, most military targets are strong IR emitters due to their high temperatures.[12] This is perhaps the greatest advantage of the IR EO system since it allows passive detection and imaging of militarily significant targets. [Ref. 37:p. 1.1]. The universal emittance of IR radiation also accounts for one of the most significant weaknesses of IR systems. Since all objects radiate IR at some level, a large amount of clutter exists in the IR environment from which the system has to discriminate the target. Another important disadvantage of IR systems is the strong level of atmospheric absorption and scattering of IR radiation. IR systems generally operate over much lesser ranges than RF systems due to this constraint. [Ref. 37:p. 1.2; Ref. 74:Chap. 4-5]. Finally, IR systems are strictly limited to line of sight propagation paths. [Ref. 37:pp. 1.1-1.2].

4.1.2.1. Discriminating Targets from Clutter

The discrimination of IR targets from background noise can be accomplished through a number of techniques. Wavelength/frequency (the frequency of the emitted radiation is dependent upon the emitting object's absolute temperature) can be used as a discriminator. This concept is known as chromatic filtering. [Ref. 37:p. 2.35; Ref. 74:p. 17.35-17.47, 22.95-22.10].

As illustrated in figure 3, the RF spectrum of a radar signal can be completely described in the amplitude versus frequency domain by breaking the spectrum into its Fourier components. The EO analogy is to break the IR or visual (or any other band) scene into Fourier components in the spatial fre-

[12]Some military targets can be purposely cold-soaked to make them harder to detect. For instance, a visually hidden tank can be shut off for days, making its temperature close to ambient. The tank can still be detected with a system which resolves the fine IR variations caused by differences in the heating/cooling rates of the steel tank versus the surrounding environment.

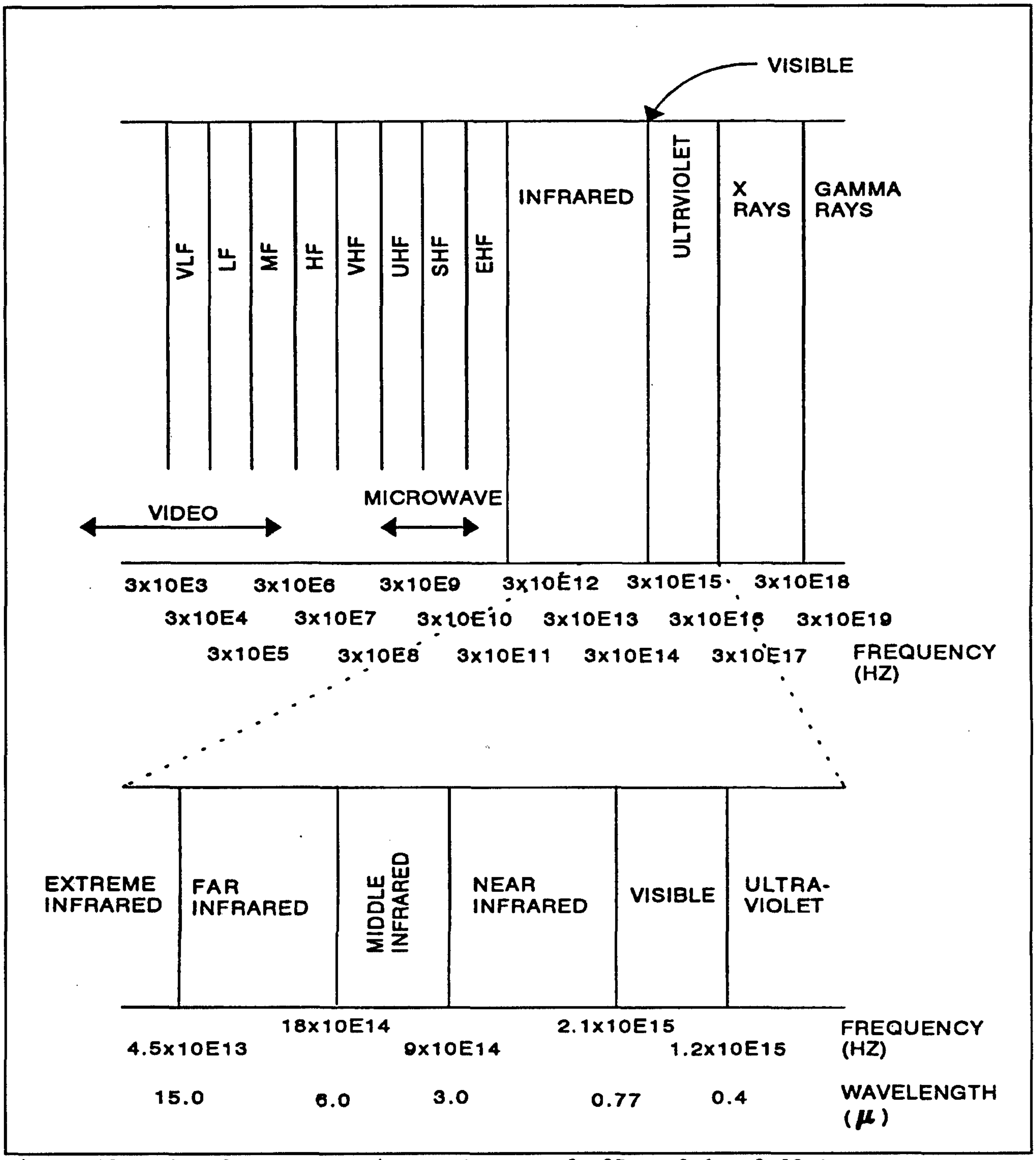


Figure 12: The Electromagnetic Spectrum [Ref. 37:pp.2.1a, 2.82a]

quency domain. Spatial frequency can be visualized as the number of times a component of a physical shape occurs over a unit of measurement. Normally, for EO systems, the units used are angular. As a simplistic example, a picket fence could be modeled with a single spatial frequency that describes the number of pickets per radian of scene. A tank, ship or series of objects, require a number of discrete Fourier components to be adequately described in the spatial frequency domain. The components can be filtered to eliminate unwanted features and thus the signal to noise characteristics of the sensor can be improved. Following filtering, the components are re-combined to present the filtered scene. [Ref. 37:pp. 2.36-2.39]. As an example of the application of the technique, an IR scene, including a ship, which is a fairly distributed source; and a flare, which approximates a point source, can be broken into its Fourier components. The flare would have a much higher spatial frequency, which could be filtered and eliminated by a low pass type filter. [Ref. 37:pp. 2.43-2.44]. The scene would then be re-combined to present the ship without the flare's presence.

When filtering in the spatial domain, (different than the spatial frequency domain) masks or reticles are used to optimize system response to targets of known dimensions. As an example, figure 13 [Ref. 37:pp. 2.42-2.43; Ref. 74:p. 17.11-17.25] depicts the response of a sensor with an Instantaneous Field Of View (IFOV) larger than, and then equal to the target. The IFOV is the angular width over which the sensor looks at any instant. In this simplified example, the system can only sense the total signal of all the emissions within the IFOV. As shown in the figure, the signal to noise ratio is highest when the IFOV matches the dimensions of the target. In this way, the signal to noise can be maximized for a target of known dimensions. [Ref. 37:pp. 2.42-2.43].

In optical time modulation, the incoming signal is time modulated in amplitude. The known modulation scheme can then be used to manipulate the signal during processing. The modulation can be provided through a number of techniques, including adding simple rotating mirrors or segmented reticles in the optical path. A typical application is in the elimination of internal noise. The signal is time modulated as it comes into the system at the reticle. Any added processing noise would not be modulated and could then be identified and filtered out.[Ref. 37:p. 2.45].

4.1.2.2. Image Scanning

In order to use powerful electronic processing devices, the IR scene must be modeled by an electrical signal. Additionally, IR sensors generally sense only the average intensity of the total IR scene within its IFOV. A larger scene is then constructed by sequentially sampling the IFOV of the sensor over the entire field of view and then combining the pieces. The sampling is usually performed at a given interval, providing direct conversion of the signal from the pure space/amplitude domain to the time/amplitude domain. The samples can then be manipulated by either digital or analog techniques using standard electronic processing devices. A simple sensor can be scanned in a grid fashion over the entire scene or a linear array can be scanned across one dimension of the scene to build the same picture. [Ref. 74:Chap. 17].

4.1.2.3. Infrared Atmospheric Transmittance

Figure 14 [Ref. 37:p. 2.10a] depicts the sea level transmittance of the atmosphere for the near to far IR band. The gaps in transmittance are due to absorption by resonant molecules such as water and carbon dioxide [Ref. 74:Chap. 5]. It is imperative that an operating wavelength for any IR detection system be chosen that falls within one of the "windows" of high transmittance. [Ref. 37:pp. 2.10-2.17]. This restriction can occasionally conflict with the desire for temporal filtering of military targets that have a maximum emittance within a gap of poor transmittance.

4.1.2.4. Radiation Detectors

Radiation detectors are at the heart of any IR system. Radiation detectors sense the average level of radiation within their IFOV and then convert this to an electrical signal. This facilitates the conversion of the spatial domain scene into the electrical time domain for further electrical/ electronic processing. The detectors can be used singly and scanned in two dimensions to build the entire "picture", used in a linear array and scanned in one dimension or used in a two dimensional array to build the picture without scanning [Ref. 74: Chap. 11]. In practice, single detectors and two dimensional arrays are rarely used. [Ref. 37: p. 2.52].

Radiation detectors are of two types. Thermal detectors absorb radiant energy and subsequently increase in temperature. Detection is performed by measuring the change of some property of the detection material resulting from the change in temperature. Common thermal detectors include [Ref. 74:p. 11.7; Ref. 37:p. 2.52]:

Pyroelectric
Thermopneumatic
Evaporagraphic
Thermovoltaic
Balometric

Photon detectors rely upon the direct effects of photons of radiant energy as

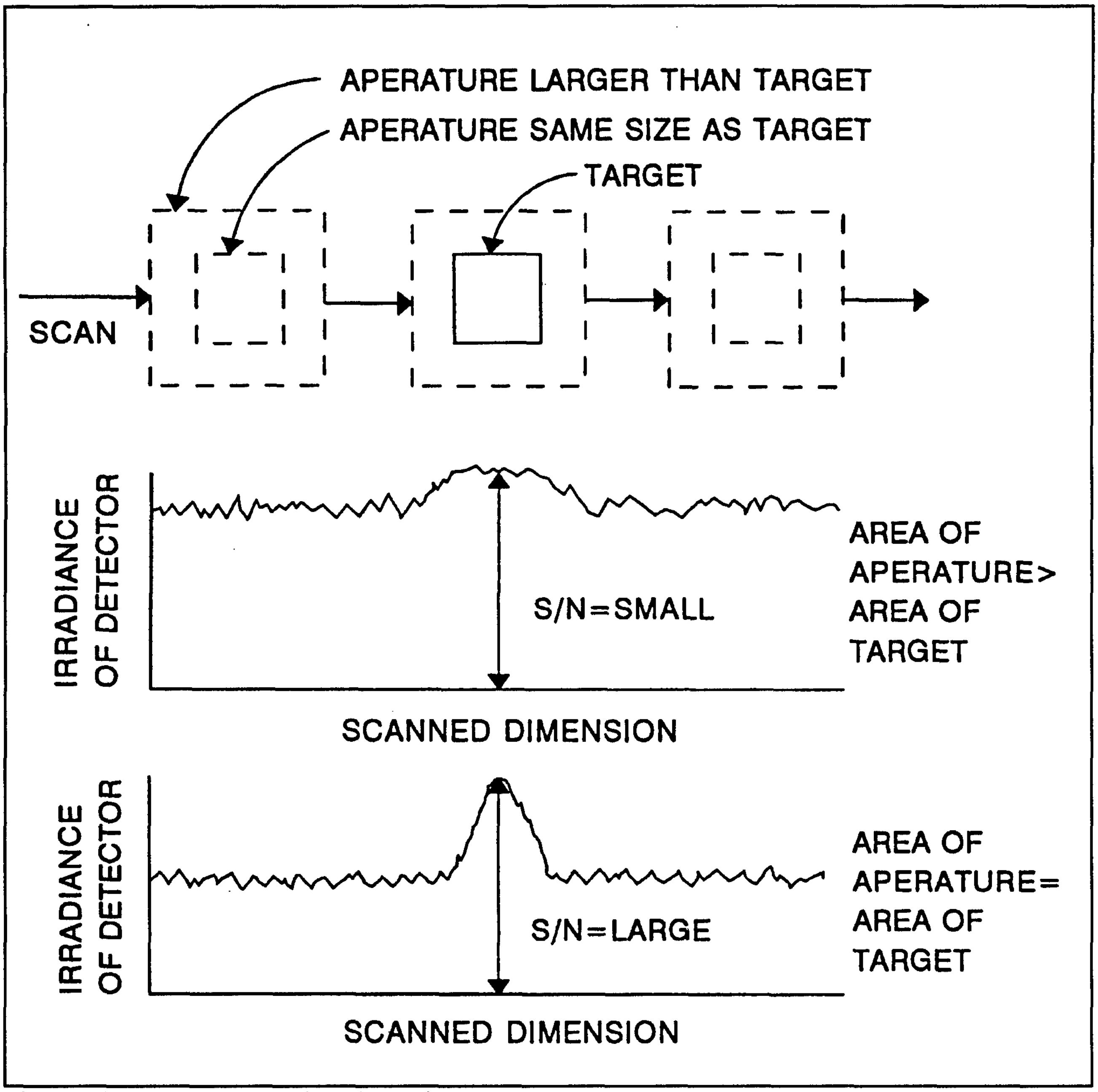


Figure 13: Space Domain Filtering

they react with the detector material. The effects are measured as an indication of the level of incident photons. [Ref. 37: p. 2.52]. Common photon detectors include [Ref. 37: p. 2.52; Ref. 74: p. 11.7]:

Photoemissive
Photoconductive
Photovoltaic
Photoelectomagnetic
Photographic

The signal to noise ratio of photon detectors is greatly increased when the detectors are cooled. Cooling as closely as possible to absolute zero reduces the amount of noise generated by the detector itself. Internally generated noise is indistinguishable in most cases from the received IR from the outside scene. Supercooling of the detectors greatly increases the performance of the detectors. Most IR detectors are cryogenically cooled using liquid gasses such as nitrogen or helium to temperatures around 4.2° to 77° K [Ref. 74: p. 15.6].

4.1.2.5. Forward Looking Infrared Radar

Figure 15 [Ref. 37:p. 2.9] depicts the IR, EO system to be used for development of the sample test techniques. This Forward Looking Infrared Radar (FLIR) is typical of many air to ground systems in operational use today. The conversion of incoming IR radiation from the external scene to a visible light representation occurs in three steps. First, the IR radiation is collected at the reticle and scanned onto the IR detectors. Next the detected IR scene is converted to the visual spectrum and scanned onto a television camera. Finally the visual spectrum output is converted by the television camera into a displayable format.

The IR radiation enters the FLIR through the reticle. The radar analogy of the reticle is the antenna. The sample reticle has two operating modes. In the Wide Field Of View (WFOV), the incident IR is unmagnified and is processed as a one to one representation of the outside world. In the Narrow Field Of View (NFOV) the incident radiation is magnified ten fold through a series of simple lenses.

The sample system uses a linear array of 186 IR detectors and so some method is required to scan the remaining dimension and build the two dimensional representation of the IR scene. This is facilitated by a rotating mirror. As the mirror rotates in the optical path, it reflects radiation onto the detectors proportional to the instantaneous level of incoming IR. Thus, the two dimensional IR scene becomes 186 analog signals. These 186 signals are then amplified and sent to 186 corresponding Light Emitting Diodes (LEDs) which emit light in the visible spectrum proportional to the incoming analog signal. Since the corresponding LED array is also linear, the visible light must be scanned identically to the IR scanning process to convert to a two dimensional representation. Perfect synchronization with the IR scanning process is required to insure a true visible spectrum representation of the IR scene. Perfect synchronization is insured by using a two sided mirror to scan the IR scene and using the back side of the mirror to simultaneously scan the LED generated scene. The visible spectrum scene is generated in two dimensions directly onto a video camera. The operator then views the scene generated by the camera as displayed on a cockpit CRT. The camera is necessary to provide the proper scan conversion from the analog visual display to the digital CRT display.

The scanning process described above determines the dimensions of the IFOV[13] of the sensor. The IFOV of the sample system is 15° horizontally by 10° vertically in the WFOV and 1.5° by 1° in the NFOV. The entire sensor is mounted in a three-dimensionally gimballed sphere, allowing the IFOV to be slewed through 200° left and right of the aircraft centerline and 20° up to 90° below the aircraft fuselage reference line. While slewing the sensor through the allowable limits, a portion of the IFOV at various gimbal positions is hidden by portions of the aircraft structure. The complete angular limits through which an object can be viewed through the FLIR exclusive of the areas masked by aircraft structure is the FLIR field of regard.

Two stabilization modes are available for the sample FLIR. In the fuselage stabilized mode the IFOV (the gimballed sphere) is held at selected angles as measured from the aircraft fuselage reference line. As the aircraft maneuvers, the IFOV center simultaneously moves as referenced to earth stabilized axes. Additionally, as the aircraft flies a groundtrack, the IFOV center translates along a groundtrack (assuming the FLIR is looking down) in a similar fashion. This stabilization mode is used when detection along the aircraft flight path is desired. Navigation FLIRs scan in this manner since it allows a real time update of the scene ahead of the flight path.

In the geographically stabilized mode, as the operator slews the FLIR to cover a desired scene, feedback from the aircraft INS is used to maintain the FLIR orientation relative to a fixed earth reference. The angles of orientation relative to the aircraft vary as the aircraft maneuvers. This stabilization mode has utility in targeting since it allows for viewing in

[13] The critical reader will note an inconsistency between the definition of IFOV used here and the definition provided earlier. By consensus, IFOV may be used to describe the angular limits of the scene projected upon the system detector array. Additionally, it is often used to describe the angular limits of the total scene covered by an imaging system with the reticle head fixed at one position. Typically, the reader must determine which definition is applicable by examination of the current context. The latter definition will be used subsequently in this book.

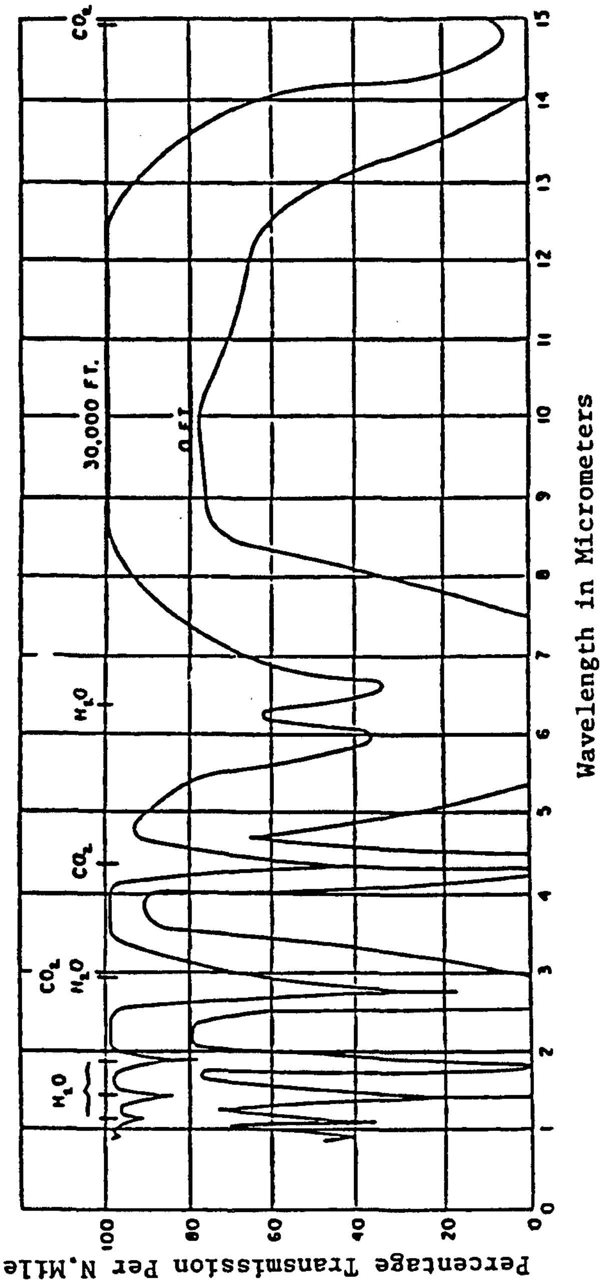


Figure 14: Infrared Atmospheric Transmittance at Sea Level [Ref.36:p.2.10a]

the direction of a target, even while maneuvering.

In most cases, the greatest source of stabilization errors for the geographically stabilized mode is the determination of the height of the aircraft above the point on the target where the FLIR crosshairs are placed. Often a manual input of target elevation is used or an assumption is made that the target is at sea level so that aircraft altitude from the navigation system can be used to partially stabilize the FLIR in three dimensions. Since an exact tapeline height above the target is not available, errors accrue and the crosshairs drift depending upon the accuracy of the approximations. Geographic stabilization is often

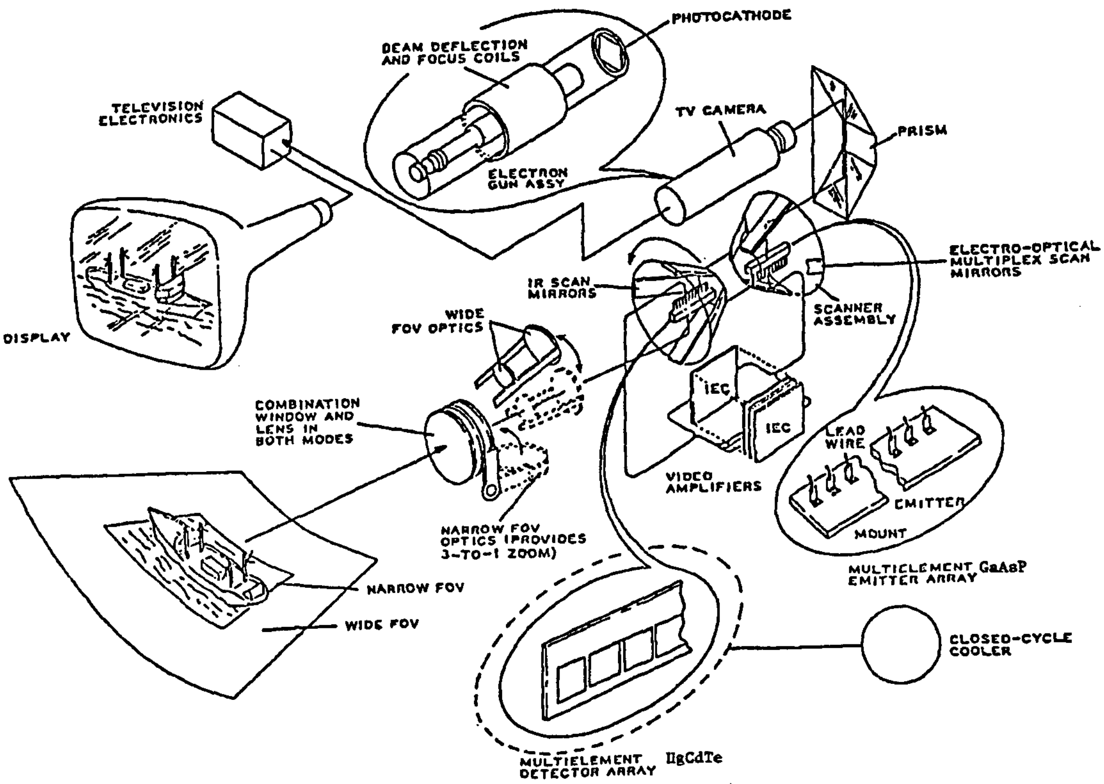


Figure 15: Sample Forward Looking Infrared Radar [Ref.37:p.2.9]

coupled with a ranging system such as radar or a Light Amplification through Stimulated Emission of Radiation (LASER) ranger. The range data is used to correct INS errors and enhance the stabilization of the FLIR on top of the target. The FLIR derived angles and radar or LASER derived ranges can also be used for targeting. Accurate angular measurement of the center of the FLIR IFOV and accurate alignment of the radar or LASER boresight with the FLIR is critical in these systems. For illustrative purposes, the sample system uses INS derived height above sea level as the default height above the target. The operator may manually enter a target height above sea level. When provided, target height is subtracted from the INS height to derive height above the target. No LASER range or coupled radar modes are available.

In most cases, FLIR displays are monochrome. Two options are available for display of the IR scene. Hot objects can be displayed as a lighter color against a darker, cool background (white hot) or as a darker color against a lighter, cool background (black hot). Hot objects are more precisely objects that emit larger amounts of IR radiation than their backgrounds. The utility of the two modes varies with the tactical situation and the type of target, and so most systems provide operator selection of the desired mode. The sample system used to develop the FLIR test procedures uses a CRT display. In addition to the FLIR video derived directly from the camera, several auxiliary display fields are multiplexed onto the CRT. The sample system provides a cross at the boresight center to facilitate centering the FLIR during targeting. Additionally, the horizontal angle from the aircraft centerline to the FLIR boresight is displayed along the bottom of the CRT and the vertical angle from the aircraft fuselage reference line to the FLIR boresight is displayed along the left side of the CRT.

With the exception of FLIRs set at fixed boresights, the operator must have some means to control the center of the FLIR IFOV. In the sample system, a joystick hand controller is used. The controller is used in three situations. In the fuselage referenced mode, the hand controller is used to adjust the boresight angle from the fuselage. In the geographically stabilized mode, the hand controller is used to center the FLIR over a geographic point that remains stabilized with reference to the earth angles excluding errors caused by the tapeline height above the target. After placing the FLIR crosshairs over the target of interest, the inertial feedback system maintains alignment on the target.

4.1.3. Electro-Optical System Human Factors

As in the radar human factors section, no attempt will be made to completely cover the topic of ergonomics[14]. As with radar systems testing, electro-optical systems testing must be performed while seated at the DEP and wearing a full set of personal flight equipment. The procedure for finding the DEP was explained in the radar theory section. The anthropometric measurements and flight gear worn by the evaluator must be recorded.

4.2. ELECTRO-OPTICAL SYSTEMS TEST TECHNIQUES

4.2.1. Preflight and Built in Tests

4.2.1.1. Purpose

The purpose of this test is to assess the suitability of the FLIR preflight and turn on procedure and the BIT to quickly and easily bring the FLIR on line and insure an operating system once airborne.

4.2.1.2. General

As airplanes become more expensive, fewer and fewer will be available to accomplish each mission, amplifying the loss of individual airplanes to inflight failures. Quick, accurate ground preflight tests are essential to determine system status while repairs can still be made. A quick response/ alert time is also important and so these checks must be expeditious and must allow the operator to prepare for the mission with a minimum of distractions. Limited airplane availability also implies the need for quick turn arounds to send the same aircraft out for successive missions. This necessitates a very short preflight and turn on procedure that can be accomplished safely and thoroughly before a hurried combat mission. In the case of a FLIR, the time required for the cool down phase of the IR detectors is often the most time consuming portion of the turn on sequence; although, some very new systems use open loop coolers with much quicker cool-down times.

4.2.1.3. Instrumentation

A stop watch and data cards are required for this test. A voice tape recorder is optional.

4.2.1.4. Data Required

Record qualitative comments, time to complete the preflight/turn on and time to complete the BIT. A record of BIT indications is required. If a separate discrete is available announcing the completion of the cool down sequence, record the time to obtain this advisory.

4.2.1.5. Procedure

Perform a normal system turn on before each test flight using the published system check list. Note the times of FLIR cool down and time out and the total system preflight time up to the ready for operate indications. Perform a preflight BIT, noting the total BIT time and indications. Note any correlation between the BIT indications and the FLIR's operation. Perform a complete system check out of the failure indications while on the ground. Make qualitative comments as appropriate.

4.2.1.6. Data Analysis and Presentation

The time and complexity of the preflight procedures listed in the operator's

[14] Wolfe and Zissis provide a discussion of IR display issues [Ref. 31: Chap. 18]

checklist and FLIR turn-on/cool-down/timeout procedure should be related to the expected alert launch time requirements and the overall operator workload during the alert launch. The BIT times and the amount of operator interface required to perform the BIT should be assessed in the same scenario. Clarity of the BIT indications should be related to the cockpit environment. The BIT indications should be related to actual FLIR degradation and verified by ground technicians. Erroneous BIT false alarms should be noted and related to the probability of unnecessarily missed sorties. Some turn on procedures are strictly serial, requiring that turn on, cool down and BIT be performed in a specific order without overlap. The turn on, cool down and BIT may be individually quick and easy, but together, may delay alert launches. In this case, relate the total of all the times to the requirement to make alert launches in a timely manner.

4.2.1.7. Data Cards

Sample data cards are presented as cards 55 and 56.

CARD NUMBER ___

PREFLIGHT/TURN ON

CLARITY OF CHECKLIST INSTRUCTIONS:

LOGICAL SEQUENCE OF CHECKLIST:

THOROUGHNESS OF CHECKLIST:

SYSTEM STATUS/COOLDOWN/TIMEOUT COMPLETE INDICATIONS:

FLIR TIMEOUT TIME____________________
FLIR COOL DOWN TIME ____________________

TOTAL PREFLIGHT TIME INCLUDING COOL DOWN/TIMEOUT________________

Card 55: Preflight/Turn On Data Card

CARD NUMBER ___

BUILT IN TESTS

INITIATION PROCEDURES:

RUN/FINISH INDICATIONS:

BIT FAILURES AND QUALITATIVE FUNCTIONAL ASSESSMENT OF THE FLIR/RESULTS OF GROUND MAINTENANCE CHECKS:

Card 56: Built In Tests Data Card

4.2.2. Controls and Displays

4.2.2.1. Purpose

The purpose of this test is to assess the suitability and utility of the FLIR controls and displays for the assigned mission as an interface between the operator and the FLIR system.

4.2.2.2. General[15]

As good as many FLIRs are in generating a visual representation of the IR scene, they have failed if the operator is not presented with a usable display or if the operator is not given adequate controls to operate the system. The controls and displays must be usable in every conceivable flight regime, ambient lighting condition, weather condition, and by aviators with the range of anthropometric measurements for which the system was designed to operate. For the modern fighter or attack airplane this is usually all weather, day or night, around +9 to -4 gs, for the 3 to 98 percentile groups, and in a realistic tactical environment filled with urgent decisions demanding the aviator's attention. For this reason, the controls and display should require an absolute minimum of operator input or interpretation and the information imparted and required from the operator should be kept at a minimum and precisely what the aviator needs to execute the current phase of flight.

Controls should be easily manipulated wearing the proper flight clothing. The range of control (both the physical range of movement of the knob, dial, lever, etc. and the range of effect that the control has on the FLIR) and sensitivity should be compatible with the expected flight regime. Controls that require manipulation while airborne should be reachable from the DEP, particularly if they must be activated in a combat environment. As an example, the FLIR targeting mode controls must be reachable while performing high g maneuvers and while maintaining a body position ready for a safe ejection. An accurate FLIR update of the target position is essential for targeting inputs to the weapons release computers. The operative sense must be correct. This means that the direction of activation should conform to the standards of common sense (turn the knob to the right to turn on the system) and to the standards set in references 12 and 13 (which for the most part merely put on paper the standards of common sense).

The FLIR line of sight slew controls often present a problem in selection of the correct operative sense. These difficulties sometimes do not become apparent until the controls are manipulated in a mission relatable fashion. The operation of the controls should be clear, requiring a minimum of operator concentration and attention. This leaves the operator free to make tactical decisions. The controls should be placed in logical functional groups, reducing the area of scan required to check the FLIR set up. The FLIR controls should be integrated well into the cockpit. This means that the FLIR controls should operate harmoniously with the other controls within the cockpit and without hindering the simultaneous operation of other airplane systems. Mission relatable hand offs between the radar and FLIR and between the different stabilization modes of the FLIR should be performed.

The integration must be evaluated during a mission relatable workload and while simultaneously operating all the other airplane systems. This is important since good FLIR work is usually just a part of the mission. Lastly, the controls should provide good tactile feedback. For example, detents should provide the proper amount of "click" and all the knobs shouldn't feel exactly alike when reaching for a control with eyes on the FLIR display. Applying a little common sense and manipulating the controls in a mission relatable environment usually uncovers most of the control human factors violations.

Many modern aircraft have a large number of the avionics controls included in the Hands-On-Throttle-And-Stick (HOTAS) format, allowing manipulation without releasing the throttle and stick. These implementations have their own human factors challenges. Typical problems

[15] For an introduction into controls and displays human factors, see references 20, 54 and 73.

include the mounting of too many controls in the available area, appropriate control sensitivity across broad flight conditions and tactile feedback considerations.

The FLIR displays should be clearly visible from the DEP in bright daylight as well as complete darkness. In bright daylight, the display must be usable under all conditions of glare including sunlight directly over the operator's shoulder onto the display (a particularly serious problem for most displays). In the dark, the display should not be so bright that it distracts the operator or affects his or her night vision. A good range of the brightness control that integrates harmoniously with the rest of the cockpit is required. The display resolution must be matched to the FLIR resolution. The display should be able to provide a "picture" quality presentation that is similar in appearance to a visual scene, accounting for the fact that the display is actually a visual representation of IR.

The display must refresh itself quickly enough so that the symbology, alphanumerics and video present an even and continuous display without noticeable flicker. Alphanumerics must be clear and legible. The messages should be short and easily understood without excessive coding or operator interpretation. The information displayed to the operator, including video, symbols and alphanumerics must be sufficient for the current phase of flight while at the same time not overloading the operator with information. This usually requires tailoring the display to the specific attack mode/mission/phase of flight, that is currently being used. The display should be assessed for the information load in a mission relatable scenario to determine its utility as an aid in the combat environment. Since the display of FLIR information approximates the visual world, the display should provide sufficient information so that the FLIR does not disorient the operator as to the attitude of the aircraft. This usually requires an easily visible and interpretable display of the FLIR line of sight orientation.

It is unlikely that a display compatible in size, weight, power and cooling requirements with a tactical airplane will be built in the near future that has too large of a usable display face. Thus, the display should be evaluated for size in a relatable mission environment, accounting for this element of realism. The display should be positioned in a location suitable for the mission. As an example, a display for a FLIR that includes targeting modes should be high on the front panel, or even on the HUD, to allow the pilot to glance down or look through the HUD and gather the FLIR derived information while at the same time minimizing the time he or she spends with his or her eyes in the cockpit and consequently away from his or her visual scan for the target. As with controls, display human factors problems typically surface by applying a little common sense while using the FLIR in a mission relatable scenario.

4.2.2.3. Instrumentation

A tape measure and data cards are required for this test. A voice recorder is optional.

4.2.2.4. Data Required

Record qualitative comments. Record the evaluator's anthropometric data and a list of personal flight gear worn. A description of the FLIR line of sight orientation displays must be recorded. The usable display area should be measured. Location of the display from the DEP should be measured if a qualitative problem is noted. Reach length of controls that are beyond the operator's reach while seated at the DEP during any mission relatable scenario must be noted.

4.2.2.5. Procedure

Find the DEP as outlined in the radar theory section. All ground and airborne tests should be performed while at this position and wearing a complete set of flight gear. Perform a system turn up on the ground outside of the hangar in a range of ambient lighting conditions (bright daylight to darkness which may be simulated using a canopy curtain). Manipulate all the controls noting the factors discussed above. Measure the display usable area. Evaluate the display for the factors discussed above. Note and measure the position and reach to all controls and displays that pose a visibility or reach problem from the DEP. During airborne testing, manipulate the controls and make qualitative comments during mission relatable attacks and intercepts. Take particular note during the extremes of ambient lighting for displays and during high g maneuvers for controls. Confirm the ground checks for reach and visibility during these circumstances. Check the extremes of control limits and sensitivity. Repeat for each test flight.

4.2.2.6. Data Analysis and Presentation

Present a table of the operator's anthropometric data and the personal flight equipment worn during the tests. Present the seat position as the number of inches from the bottom of the seat travel. Relate the sensitivity of the controls to the tactical environment in which they are to be used. For example, an attack airplane's slew control may be too sensitive to use for an accurate update of the target position under moderate g or turbulence making it unusable while maneuvering for an attack. Relate the accessibility, placement and grouping of the controls under mission relatable conditions. An attack mode selector must be readily accessible while scanning outside the airplane and maneuvering violently. Relate the control clarity, operative sense and tactile feedback to a multiple threat, combat scenario requiring the operator to make quick tactical decisions. If ambient lighting affects the display in any way, relate this to the limits of the possible combat environments. Compare the display resolution to the "picture" quality of the IR scene.

Relate the information load presented the operator to the combat scenario discussed above and evaluate whether the needed information is present and whether too much information is cluttering the display. This information can include FLIR video, alphanumerics or symbols. This concept is closely related to the size of the display face usable area. A large scope can present more information without cluttering the display and requires less concentration to read and evaluate. The refresh rate should be related to the concentration required to evaluate a lagging display. The utility of the FLIR line of sight orientation displays should be related to the likelihood of the display disorienting the pilot and causing him to make improper adjustments to the aircraft's attitude. The display position should be evaluated considering the type of information involved, the eye position required for using the display and the display position's effect upon scan.

4.2.2.7. Data Cards

Sample data cards are presented as cards 57 and 58.

CARD NUMBER ___

CONTROLS

CLARITY OF OPERATION:

ACCESSIBILITY (MEASURE REQUIRED REACH IF A PROBLEM):

OPERATIVE SENSE:

ADJUSTMENT SENSITIVITY:

RANGE OF ADJUSTMENT:

TACTILE FEEDBACK:

FUNCTIONAL LOCATION/GROUPING (SKETCH IF A PROBLEM):

INTEGRATION:

Card 57: Controls Data Card

CARD NUMBER ___

DISPLAYS

[PERFORM IN BRIGHT DAYLIGHT TO DARKNESS.]

LOCATION QUALITATIVE COMMENTS (MEASURE LOCATION IF A PROBLEM):

CONTRAST/BRIGHTNESS/GAIN CONTROLS (RANGE OF EFFECTIVENESS):

GLARE (BOTH FROM OUTSIDE AND INSIDE COCKPIT LIGHT SOURCES):

RASTER LINES/INCH________

USABLE DISPLAY AREA _____X_____

RESOLUTION QUALITATIVE COMMENTS:

REFRESH RATE QUALITATIVE COMMENTS:

LOCATION OF SYMBOLOGY/ALPHANUMERICS:

INTERPRETATION OF SYMBOLOGY/ALPHANUMERICS:

UTILITY OF FLIR LINE OF SIGHT ORIENTATION DISPLAYS:

INTEGRATION:

Card 58: Displays Data Card

4.2.3. Instantaneous Field of View

4.2.3.1. Purpose

The purpose of this test is to measure the IFOV of the FLIR in all field of view selections and to assess the utility of the range of IFOV selections for the assigned mission.

4.2.3.2. General

Most modern FLIRs are used for navigation and targeting when visibility is reduced. During navigation, a wide IFOV is desirable to provide as much of a panoramic view as possible as the aircraft moves along its course. As a targeting tool, a narrow IFOV with some amount of magnification is desirable to allow maximum accuracy in targeting data. Target search requires something in between to allow for a reasonable search area while still providing enough magnification to identify the target at mission relatable ranges. Note that in the context used here, a narrow IFOV implies magnification of some portion of the incoming IR scene.

4.2.3.3. Instrumentation

A tape measure and data cards are required for this test. A voice recorder is optional.

4.2.3.4. Data Required

Record the distance from the FLIR aperture to the wall. Record linear measurements of the vertical and horizontal field of views as marked on the wall for each IFOV selection. Include qualitative comments concerning the utility of the IFOV selections during navigation, target search and FLIR targeting.

4.2.3.5. Procedure

Park the test airplane with the nose pointed at a wall. Turn on and time out the FLIR, focusing it onto the wall at a point where the wall is perpendicular to a line extending from the FLIR aperture. Select the WFOV and have an assistant place a chalk mark at the intersection of the FLIR crosshairs. Close communication will be required as the assistant finds the location of this point. Have the assistant then mark the four corners of the IFOV of the FLIR in a similar fashion. Use the tape measure to determine the distance in inches from the FLIR aperture to the crosshair intersection mark (l). Measure the horizontal (h) and vertical (v) measurements of the box formed by the corners of the IFOV marked by the assistant. Repeat for the NFOV. While airborne, perform mission relatable FLIR navigation to the target area making qualitative comments on the utility of the WFOV for navigation and orientation. Use the fuselage stabilized and geographically stabilized mode as required during the test. Following navigation to the target area, make qualitative comments concerning the utility of the WFOV and NFOV for detecting and identifying the target and in the NFOV make comments concerning the utility for making accurate updates of the cursors over the target position.

4.2.3.6. Data Analysis and Presentation

Use equation (28) to find the horizontal and vertical IFOV ($IFOV_h$, $IFOV_v$) in both NFOV and WFOV.

$$\begin{aligned} IFOV_h &= \arctan\left(\frac{h}{l}\right) \\ IFOV_v &= \arctan\left(\frac{v}{l}\right) \end{aligned} \tag{28}$$

Relate the utility of the WFOV for FLIR navigation to the possibility of pilot disorientation as he or she attempts to navigate without enough of the outside scene available for view and to the possibility of impacting obstructions outside of the field of view. Relate the utility of the WFOV and NFOV for detecting and identifying the target to the probability of missed attacks and missed targets. Relate the utility of the NFOV for targeting to the highly accurate updates required to place ordnance on a target.

4.2.3.7. Data Cards

Sample data cards are provided as card 59.

CARD NUMBER ___

INSTANTANEOUS FIELD OF VIEW (GROUND TEST)

[POSITION THE AIRCRAFT CLOSE TO A WALL AND POINT THE FLIR AT A SPOT WHERE THE WALL IS PERPENDICULAR TO THE LINE FROM THE FLIR TO THE WALL. HAVE AN ASSISTANT MARK THE CROSSHAIRS AND CORNERS.]

	WFOV	NFOV
DISTANCE FROM APERTURE		
TO CROSSHAIRS MARK (l)		
VERTICAL DIMENSION (v)		
HORIZONTAL DIMENSION (h)		

Card 59: Instantaneous Field of View Data Cards

CARD NUMBER ___ TIME _____ PRIORITY L/M/H

INSTANTANEOUS FIELD OF VIEW (AIRBORNE TEST)

[DESCEND TO ___ FEET AGL AND SET MACH=__. SELECT WFOV AND THE FUSELAGE REFERENCED STABILIZATION MODE, SWITCHING TO THE GEOGRAPHICALLY STABILIZED MODE AS REQUIRED. START AT __________ AND NAVIGATE INBOUND TO THE __________ TARGET. FIND THE TARGET USING THE WFOV AND IDENTIFY USING THE NFOV. USE THE NFOV TO PROVIDE TARGETING, UPDATING THE FLIR CURSOR PLACEMENT AS REQUIRED. PERFORM A __________ DELIVERY. REPEAT WITH DIFFERENT DELIVERY MODES AS TIME ALLOWS.]

COMMENTS:

Card 59: Instantaneous Field of View Data Cards (Continued)

4.2.4. FLIR Slew Limits

4.2.4.1. Purpose

The purpose of this test is to measure the vertical and horizontal slew limits of the FLIR and the utility of these limits for providing a target display while the aircraft maneuvers to the target and for searching a sufficiently wide area around the aircraft ground track and attitude.

4.2.4.2. General

The IFOV defines the area of the scene that the FLIR can display at a given instant. There will be some physical limits over which the gimballed ball containing the FLIR reticle can be slewed, thus limiting the search volume of the FLIR and the angles from the fuselage reference line that a scene can be displayed. These limits are usually defined both vertically and horizontally and for tactical aircraft are typically 100° left and right, 20° up and 90° down as measured from the fuselage reference line. A final constraint on the scene's volume that can be displayed is the area masked by the aircraft fuselage and other obstructions. This last constraint will be evaluated during the field of regard test to follow. The symmetry of the display, that is, the correct alignment of the physical limits with the fuselage reference line, will be determined during the FLIR pointing accuracy test. The slew limit tests will provide only the total angle between the left and right and up and down slew limits.

4.2.4.3. Instrumentation

A protractor, plumb bob, cord, tape measure, level and data cards are required for this test. A voice recorder is optional.

4.2.4.4. Data Required

While on the ground, record the angle from the position of the display crosshairs with the FLIR slewed completely to the left to the position of the crosshairs with the FLIR slewed completely to the right. Record the angle from the position of the display crosshairs with the FLIR slewed fully up and the angle of the crosshairs from vertical with the FLIR slewed fully down. Make qualitative comments concerning the utility of the slew angle limits while performing mission relatable evasive maneuvers and attacks.

4.2.4.5. Procedure

Park the airplane with the fuselage reference line perpendicular to a wall. Turn on and time out the FLIR. Use the plumb bob to find and mark a point on the ground directly below the swivel point of the reticle. Slew the FLIR fully left. Have an assistant adjust the position of the plumb bob until it corresponds with the vertical crosshair of the FLIR. Mark the point where the plumb bob reaches the ground. Note that close communications are required between the evaluator in the aircraft and the assistant. Repeat for the right slew limit. Stretch a cord from the mark on the ground below the FLIR to the left mark and to the right mark. Use the protractor to measure the angle between the two cords. Next, slew the FLIR fully down and have the assistant mark the intersection of the crosshairs on the ground. Stretch a cord from the direction of the center of the FLIR reticle swivel point to the point on the ground. Have the assistant use the level to adjust the protractor perpendicular to local vertical and measure the angle from the string to local vertical (down). Repeat for the upper slew limit point, marking the point on the wall ahead of the aircraft and using the level, protractor and string to measure the angle from horizontal as defined by the level.

While airborne, perform mission relatable attacks against a simulated ground target, jinking as would be required during an attack and maneuvering to perform a weapons delivery. Note if the FLIR slew limits are reached while slewing the FLIR to maintain contact with the target. Repeat for a variety of maneuvering weapons deliveries.

4.2.4.6. Data Analysis and Presentation

Add the upper and lower slew limit measurements to obtain the vertical slew limits. Relate the slew limits to the necessity to jink inbound to the target to avoid enemy defenses as well as to the requirement to maneuver during various weapon deliveries such as iron bomb lofts and to the necessity to maintain FLIR contact with the target during the deliveries.

4.2.4.7. Data Cards

Sample data cards are presented as card 60.

CARD NUMBER ___

FLIR SLEW LIMITS (GROUND TEST)

[POSITION THE AIRCRAFT WITH THE FUSELAGE REFERENCE LINE PERPENDICULAR TO A WALL. HAVE AN ASSISTANT USE A PLUMB BOB TO MARK DIRECTLY BELOW THE CENTER OF THE RETICLE BALL SWIVEL POINT, THE POINT ON THE GROUND BELOW THE LEFT AND RIGHT SLEW LIMITS AND THE POINT ON THE WALL AND FLOOR FOR THE UPPER AND LOWER SLEW LIMITS. USE CORDS TO MEASURE THE DIFFERENCE BETWEEN THE LEFT/RIGHT LIMITS AND THE ANGLES FROM LOCAL VERTICAL FOR THE UPPER AND LOWER LIMITS.]

LEFT TO RIGHT ANGLE _____

UPPER LIMIT ANGLE _____

LOWER LIMIT ANGLE _____

Card 60: FLIR Slew Limits Data Cards

CARD NUMBER ___ TIME _____ PRIORITY L/M/H

FLIR SLEW LIMITS (AIRBORNE TEST)

[DESCEND TO ___ FEET AGL AND SET MACH=__. ACQUIRE THE __________ TARGET AND HEAD INBOUND, SELECTING THE NFOV AND UPDATING THE CURSOR PLACEMENT AS NECESSARY. PERFORM MISSION RELATABLE JINKING INBOUND AND THEN PERFORM A __________ DELIVERY. NOTE IF THE FLIR REACHES THE SLEW LIMITS. REPEAT FOR THE _________ AND __________ DELIVERIES.]

TYPE DELIVERY __________

POINT IN DELIVERY WHERE THE LIMITS ARE REACHED:

DISPLAYED FLIR POSITION

VERTICAL __________

HORIZONTAL __________

TYPE DELIVERY __________

POINT IN DELIVERY WHERE LIMITS REACHED:

DISPLAYED FLIR POSITION

VERTICAL __________

HORIZONTAL __________

Card 60: FLIR Slew Limits Data Cards (Continued)

4.2.5. Slew Rates

4.2.5.1. Purpose

The purpose of this test is to determine the vertical and horizontal maximum slew rates of the FLIR and to evaluate the effects these rates have upon the utility of the FLIR for quickly pointing to the direction of a target and then maintaining an orientation towards the target as the host aircraft maneuvers or flies in close proximity to the target.

4.2.5.2. General

The FLIR slew rates are important for three reasons. First, the operator will want to rapidly point the FLIR in the direction of targets of opportunity or towards objects that catch his or her attention. Next, as the aircraft maneuvers towards its maximum limits, the angles from the fuselage reference line to the target may change rapidly. The FLIR will have to slew rapidly to keep up with the aircraft rates. Finally, as the aircraft approaches the target, the angles from the fuselage reference line to the target will have to eventually change, unless the pilot flies a collision course to the target. Many types of ordnance require targeting data even as the aircraft passes the target and leaves the area. Even for unguided ordnance, the operator may want to continue viewing the target after an overflight to assess the damage. For a given aircraft groundspeed, the closer the aircraft passes to the target, the higher the slew rates that will be required to keep the FLIR aligned onto the target.

4.2.5.3. Instrumentation

A stop watch and data cards are required for this test. A voice recorder is optional.

4.2.5.4. Data Required

Record the time for the FLIR turret to slew from full left to full right and full right to full left. Record the time to slew from full up to full down and full down to full up. List qualitative comments concerning the utility of the FLIR for quickly slewing from a target near one slew angular limit to the opposite slew angular limit. Make comments concerning the utility of the slew rate limits as the aircraft performs evasive maneuvers within the aircraft angular slew limits for maintaining alignment with the target. Record comments concerning the utility of the slew rate limits as the aircraft flies over the target at mission relatable weapons release altitudes and performs post release maneuvers, for maintaining the FLIR alignment with the target.

4.2.5.5. Procedure

Measure the slew angular limits as described earlier. While on the ground, slew the FLIR to a full left angular limit. Slew to a full right angular limit as quickly as possible using the stop watch to measure the time. Repeat in the opposite direction. Slew the FLIR to the full down position and measure the time required to slew to a full up position. Repeat for a full up to a full down position. Close coordination will be required between the operator and an assistant if the operator is unable to accurately observe the FLIR pod slew.

During mission relatable attacks, perform evasive maneuvers inbound to the target. Evaluate the utility of the FLIR slew rates for maintaining orientation over the target position. Attempt the test first in a geostable mode and if problems are noted repeat in a manual fuselage referenced mode. Overfly the target at a mission relatable minimum altitude for weapons delivery and then perform mission relatable post-flight maneuvers. Evaluate the utility of the FLIR slew rates for maintaining alignment with the target for post-release weapons guidance and post-attack damage assessment. Perform the test first in a geostable mode and if problems are noted perform the test in a fuselage referenced manual mode. Repeat the attack using different attack modes as time allows.

4.2.5.6. Data Analysis and Presentation

Divide the horizontal slew angular limits by the number of seconds required to slew from left to right and from right to left to get the slew rate in degrees per second. The two measurements should be fairly close or a problem in the slewing mechanization may by indicated. Repeat for the upper and lower angles. There might be a slight difference in these two rates due to the effects of gravity, depending upon the slewing mechanism. Note that these are average slew rates and may vary at different points during slewing; however, in most situations where large slew rates are operationally required, large angular changes are also required and the average time found here is mission relatable. Relate the effects of the slew rate to the requirement to quickly slew to a target of opportunity that catches the operator's eye in time to set up an attack. Relate the slew rates to the requirement to keep the FLIR aligned on the target during ingress evasive maneuvers and while passing the target for post-release weapons guidance and damage assessment. If problems are not noted during the geostable attacks, the slew rates are adequate; however, if problems are noted, the test must be repeated in the fuselage referenced mode to insure the noted drifts are not a result of the geostable mode implementation.

4.2.5.7. Data Cards

Sample data cards are presented as card 61.

CARD NUMBER ___

SLEW RATES (GROUND TEST)

[FOLLOWING THE SLEW ANGULAR LIMITS TEST, MEASURE THE TIME REQUIRED TO SLEW FULL LEFT TO RIGHT AND FULL RIGHT TO LEFT. MEASURE THE TIME TO SLEW FULL UP TO DOWN AND FULL DOWN TO UP.]

LEFT TO RIGHT _____ SEC

RIGHT TO LEFT _____ SEC

UP TO DOWN _____ SEC

DOWN TO UP _____ SEC

Card 61: Slew Rates Data Cards

CARD NUMBER ___ TIME _____ PRIORITY L/M/H

SLEW RATES (AIRBORNE TEST)

[DESCEND TO ___ FEET AGL AND SET MACH=__. ACQUIRE THE __________ TARGET AND HEAD INBOUND SELECTING THE NFOV, GEOSTABLE MODE. PERFORM MISSION RELATABLE JINKING INBOUND AND THEN PERFORM A __________ DELIVERY WITH POST-DELIVERY EVASIVE MANEUVERS. NOTE IF THE FLIR REMAINS ALIGNED OVER THE TARGET TO THE SLEW ANGULAR LIMITS. IF PROBLEMS ARE NOTED, REPEAT IN A FUSELAGE REFERENCED MODE AND PROVIDE MANUAL UPDATES.]

TYPE DELIVERY __________

POINT IN THE DELIVERY WHERE THE DRIFT OCCURRED:

DESCRIBE THE MANEUVER:

AIRSPEED __________

APPROXIMATE RANGE FROM TARGET __________

TYPE DELIVERY __________

POINT IN THE DELIVERY WHERE THE DRIFT OCCURRED:

DESCRIBE THE MANEUVER:

AIRSPEED __________

APPROXIMATE RANGE FROM TARGET __________

Card 61: Slew Rates Data Cards (Continued)

4.2.6. FLIR Pointing Accuracy

4.2.6.1. Purpose

The purpose of this test is to measure the accuracy of the FLIR display horizontal and vertical pointing angle indications and their effects upon the utility of the FLIR display for orienting the operator to the actual position of the target relative to the aircraft.

4.2.6.2. General

Often the operator will want to slew the FLIR to view in detail a target that has caught his or her attention visually. Additionally, the operator may want to visually find a target he or she has detected on the FLIR. For this reason, the accuracy of the display of the FLIR pointing angles is important. Additionally, the azimuth and elevation scales are used in the measurement of the field of regard and must be verified prior to this important test.

4.2.6.3. Instrumentation

A piece of chalk, protractor, plumb bob, cord, tape measure and data cards are required for this test. A voice recorder is optional.

4.2.6.4. Data Required

Record the actual and displayed horizontal angle from the FLIR reticle to the test target over each 30° increment from the fuselage reference line to the left and right limit. Record the actual and displayed vertical angle from the FLIR reticle to the test target over each 30° increment from the plane passing through the FLIR reticle center perpendicular to the local vertical to the upper and lower limit. Record the angle from the horizontal plane to the fuselage reference line. Record qualitative comments concerning the utility of the FLIR pointing angle display accuracy for visually finding targets displayed at the FLIR crosshairs and for positioning the FLIR crosshairs over targets found visually.

4.2.6.5. Procedure

Obtain the angle of the fuselage reference line from the horizontal plane while the aircraft is sitting on its landing gear. The angle may be found within the aircraft engineering documents. The contractor for the airframe will be able to supply these angles. For the sample system, the FLIR is aligned to the aircraft fuselage reference line.

Park the airplane perpendicular to a wall, with the nose pointed at the wall and approximately 30 feet away. Use the plumb bob to mark a point on the deck with the chalk directly below the swivel point of the FLIR reticle. Use the tape measure to determine the distance from the center of the FLIR reticle swivel point to the deck. Align the cord with the longitudinal axis of the aircraft and on top of the chalk mark below the FLIR. Extend the cord in front of the airplane to the wall. Mark this spot with chalk.

Use the plumb bob and tape measure to place a small, warm object above the first spot on the wall at the same height above the ground as the reticle center. Have the operator place the crosshairs over the target and record the indications on the vertical and horizontal scales. Use the protractor to swivel the cord at 30° increments to the left to the angular limits of the FLIR and then to the right. At each point, use the plumb bob to place a target at the same approximate height as the first target and have the operator place the crosshairs over the target and mark the position on the horizontal scale. Use the cord and the protractor to mark positions on the wall and the floor at 10° above and 30° increments below the horizontal position from the FLIR swivel point. Mark points to the FLIR angular limits or as high up the wall as practicable. At each point, place a warm target, have the operator place the cursors over the target and mark the position on the vertical scale.

While airborne, visually find targets of opportunity at various positions from the aircraft. Estimate the angles to the targets and slew the FLIR to the estimated positions, acquiring the target. Next, find targets of opportunity with the FLIR and then use the scale positions to visually acquire the targets. Qualitatively assess the utility of the indications for performing these visual tasks.

4.2.6.6. Data Analysis and Presentation

Subtract the horizontal scale indications from the measured horizontal target positions. For the vertical positions, add the angle of the fuselage reference line above the horizon (or subtract for an angle below the horizon) to the measured positions of the target. Subtract the vertical scale indications from the adjusted, measured target positions. For each scale, plot the error versus the scale indications. Relate the error to the utility of the scale indications for visually finding targets first noted using the FLIR and for finding targets first noted visually on the FLIR scene.

4.2.6.7. Data Cards

Sample data cards are presented as card 62.

CARD NUMBER ______

FLIR POINTING ACCURACY (GROUND TEST)

[POSITION THE AIRCRAFT PERPENDICULAR TO THE WALL AND 30 FEET AWAY, NOSE ON. MARK THE POSITION BELOW THE FLIR SWIVEL POINT. MARK THE EXTENSION OF THE FUSELAGE REFERENCE LINE (FLR) ON THE WALL AND THE VERTICAL POINT ON THE WALL LEVEL WITH THE RETICLE. SLEW THE CROSSHAIRS OVER THE POINT AND MARK THE SCALES. REPEAT AT 30° INCREMENTS TO THE LEFT AND THE RIGHT. OVER THE NOSE OF THE AIRCRAFT, MARK POINTS 10° ABOVE AND 30° BELOW THE HORIZON LINE AND REPEAT.]

FRL POSITION ____________ ABOVE/BELOW HORIZON

CENTERLINE/LEVEL ____________/____________

HORIZONTAL SCALE

LEFT 30°	__________	RIGHT 30°	__________
60°	__________	60°	__________
90°	__________	90°	__________
120°	__________	120°	__________
150°	__________	150°	__________
180°	__________	180°	__________
200°	__________	200°	__________

VERTICAL SCALE

ABOVE 10°	__________	BELOW 30°	__________
20°	__________	60°	__________
		90°	__________

Card 62: FLIR Pointing Accuracy Data Cards

CARD NUMBER ____ TIME _____ PRIORITY L/M/H

FLIR POINTING ACCURACY (AIRBORNE TEST)

[CLIMB TO ____ FEET AGL AND SET ____ KIAS. VISUALLY FIND TARGETS OF OPPORTUNITY AND SLEW THE FLIR TO THEIR POSTIION, ACQUIRING THEM ON THE FLIR IN THE WFOV. FIND TARGETS ON THE FLIR AND ATTEMPT TO ACQUIRE THEM VISUALLY. QUALITATIVELY EVALUATE THE UTILITY OF THE SCALE ACCURACY.]

COMMENTS:

Card 62: FLIR Pointing Accuracy Data Cards (Continued)

4.2.7. Field of Regard

4.2.7.1. Purpose

The purpose of this test is to plot the field of regard for the FLIR and to assess its utility for detecting targets at mission relatable angles from the aircraft centerline.

4.2.7.2. General

The IFOV tests determined the angular measurements of the unscanned FLIR display, while the slew limits tests determined the maximum angles over which the center of the FLIR display could be slewed horizontally and vertically. A third limitation to the areas over which targets can be detected and displayed is the portion of the aircraft structure that obstructs the FLIR display. The graphical depiction of these obstructions and limits is the rectilinear plot which has linear scales of 180° left and right and 90° up and down from the center of the FLIR display. Figure 16 is a sample rectilinear plot. For the sample system, the center of the rectilinear plot will be placed over a line parallel to the fuselage reference line and translated to the center of the FLIR slew axis since this is the line upon which the crosshairs are centered when set at zero and zero on the pointing angle scales. The pointing angle scales will be used to quickly determine the angles to the obstructions but will be corrected for alignment errors using the plots derived in the pointing angle accuracy tests.

4.2.7.3. Instrumentation

A blank rectilinear plot and data cards are required for this test. A voice recorder is optional.

4.2.7.4. Data Required

Record the angular positions of the corners of each obstruction to FLIR visibility derived from the FLIR display. Draw a sketch connecting the plotted positions of the obstruction corners. Make qualitative comments concerning the utility of the FLIR field of regard for detecting the target and keeping it in view during evasive maneuvers and during post-delivery maneuvers.

4.2.7.5. Procedure

Following the FLIR pointing accuracy test, set WFOV for the FLIR and set the aircraft flaps to a position consistent with a high speed attack. This usually requires full up flaps. The aircraft should be loaded with drop tanks and external ordnance if normally carried during an attack. Use a blank rectilinear plot to mark the positions of the corners of the obstructions. Use the positions derived from the vertical and horizontal FLIR position scales to determine the corresponding positions marked on the horizontal and vertical scales of the plot. Sketch the connecting lines and verify the picture on the plot corresponds with the display. Label the obstructions to visibility. Note the positions where the landing gear would be absent when airborne. These can be deleted from the plot if desired.

When airborne, during mission relatable attacks, note the effects of the obstructions upon FLIR utility for ingress navigation, target detection and target visibility during evasive maneuvering before delivery and during post-delivery maneuvers. Repeat the test using different attack modes as time allows. The tests should be performed with mission relatable external drop tanks and carrying mission relatable real or inert ordnance.

4.2.7.6. Data Analysis and Presentation

Transpose the plot of the obstruction points to a second rectilinear plot, applying the corrections in horizontal and vertical azimuth indications found during the pointing accuracy tests. Add the visibility limitations imposed by the horizontal and vertical scan angle limits as appropriate. Re-sketch the obstructions and add the obstruction labels. The landing gear may be left in or taken out as desired. Relate the size and placement of the obstructions to FLIR visibility to the limitations they impose upon finding targets of opportunity around the aircraft and to the necessity to perform FLIR updates while also flying evasive maneuvers into the target area that may place the target into a blind area of the FLIR. Additionally, relate the size and placement of the obstructions to the requirement to maintain FLIR updates after weapons delivery for post-release guidance and post-attack damage assessment.

4.2.7.7. Data Cards

Sample data cards are provided as card 63.

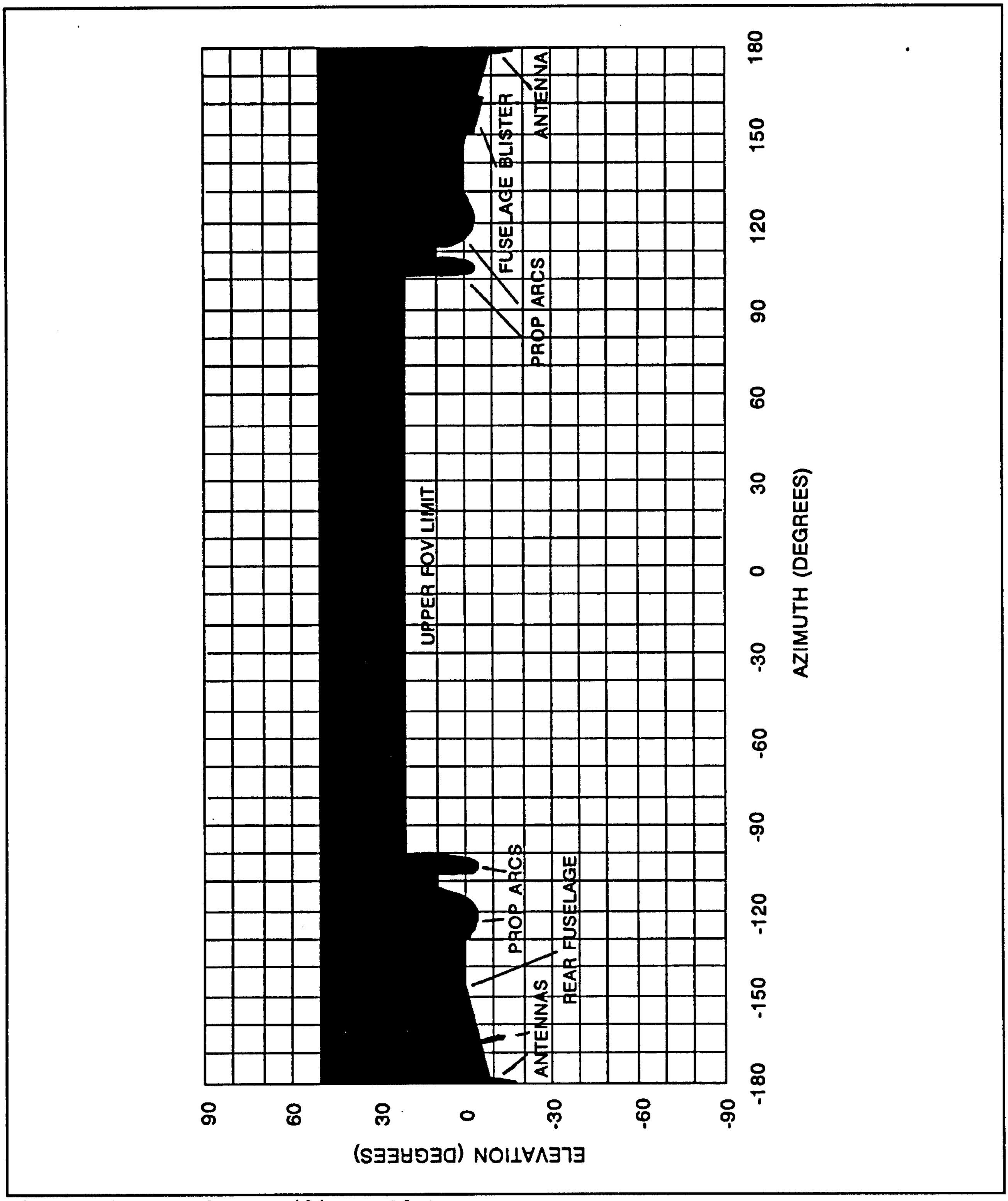
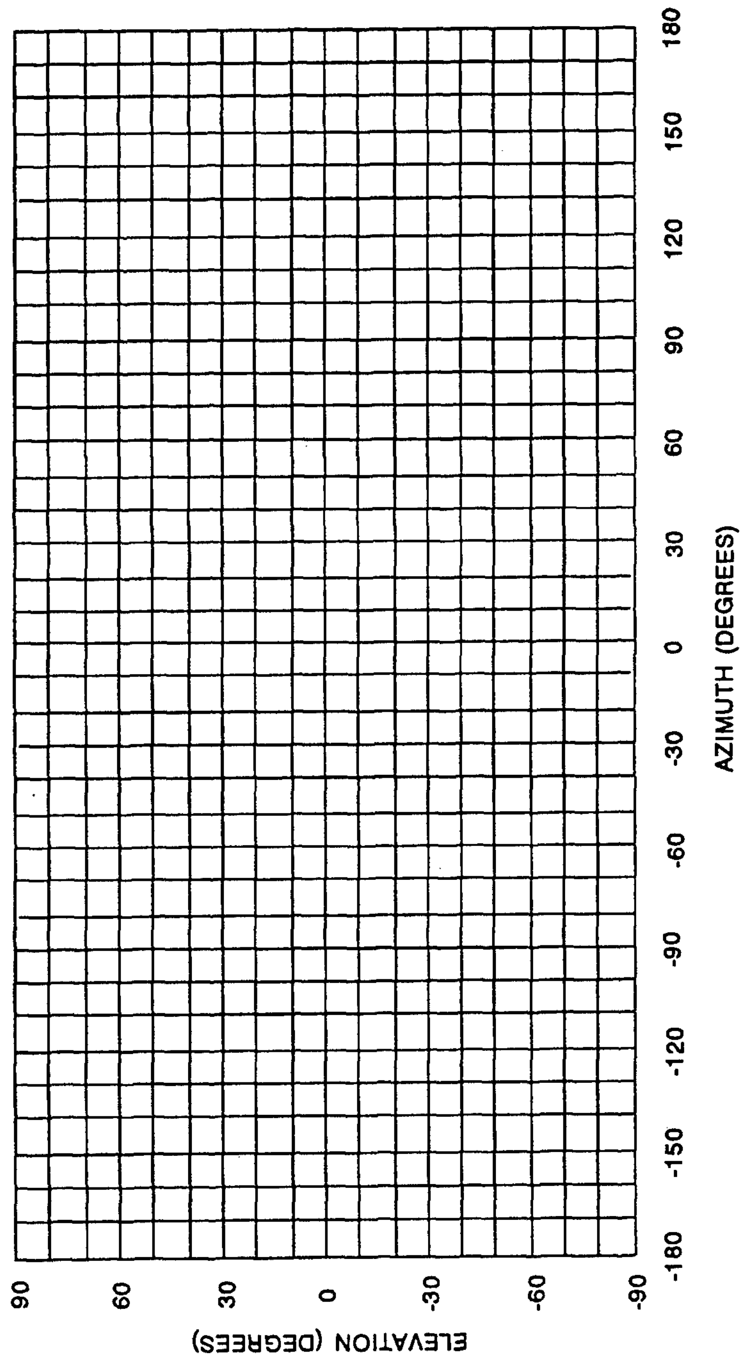


Figure 16: Sample Rectilinear Plot

CARD NUMBER ____

FIELD OF REGARD (GROUND TEST)

FLAP SETTINGS __________ EXTERNAL CONFIGURATION:



Card 63: Field of Regard Data Cards

CARD NUMBER ____TIME _____PRIORITY L/M/H

FIELD OF REGARD (AIRBORNE TEST)

[DESCEND TO ___ FEET AGL AND SET MACH=___. ACQUIRE THE __________ TARGET AND HEAD INBOUND, SELECTING THE NFOV AND GEOSTABLE MODE. PERFORM MISSION RELATABLE JINKING INBOUND AND THEN PERFORM A __________ DELIVERY WITH POST-DELIVERY EVASIVE MANEUVERS. NOTE IF THE TARGET BECOMES OBSCURED BY AIRCRAFT STRUCTURES. REPEAT IN THE __________ ATTACK MODE.]

TYPE DELIVERY __________

POINT IN DELIVERY WHERE TARGET LOST:

STRUCTURE OBSCURING TARGET:

DESCRIBE MANEUVER:

TYPE DELIVERY __________

POINT IN DELIVERY WHERE TARGET LOST:

STRUCTURE OBSCURING TARGET:

DESCRIBE MANEUVER:

Card 63: Field of Regard Data Cards (Continued)

4.2.8. Line of Sight Drift Rate

4.2.8.1. Purpose

The purpose of this test is to measure the rate at which the FLIR line of sight drifts and to assess the effects that the drift rate has upon the utility of the FLIR for maintaining the selected orientation.

4.2.8.2. General

While using the fuselage referenced stabilization mode, the FLIR line of sight may drift from the selected angles. During the geostable mode, the INS may contribute to the total drift; however, the drift inherent in the fuselage referenced mode will still be present.

4.2.8.3. Instrumentation

A tape measure, square, stop watch and data cards are required for this test. A voice tape recorder is optional.

4.2.8.4. Data Required

Record the elapsed time and horizontal and vertical drift distance for both the fuselage referenced and geostable stabilization mode. Measure the distance from the reticle to the crosshair position on the wall at the start of the test. Record qualitative comments concerning the utility of the FLIR for maintaining an operator selected fuselage referenced orientation or stabilization to a geographic point.

4.2.8.5. Procedure

Park the airplane with the nose pointed at a wall and approximately 30 feet away. Use the tape measure and square to draw a line on the wall parallel to the floor and a bisecting line perpendicular to the first. Place the intersection of the lines at any convenient point on the wall, approximately perpendicular to the FLIR reticle. Measure the distance from the FLIR reticle to the intersection of the lines. Time out the FLIR, select NFOV and fuselage referenced mode and place the crosshairs over the intersection of the lines. Start the stop watch and have an assistant mark the point at which the crosshairs are aligned at one minute intervals. Close communications between the operator and assistant will be required. Use the square to measure and record the horizontal and vertical component of the drift. Continue the test for at least 10 minutes. Repeat in the geostable referenced mode.

During mission relatable navigation to the target area and attacks, assess the utility of the FLIR for maintaining the operator selected orientation. Assess the effects that the fuselage referenced drift rate has upon the utility of the FLIR for navigation and scanning for targets of opportunity and the effects that the geostable drift rate has upon the utility of the FLIR for maintaining alignment over the target position during an attack. Pay particular attention to the effects of the required FLIR updates upon operator workload.

4.2.8.6. Data Analysis and Presentation

Convert the linear horizontal and vertical drift distances to angles using the equation below:

$$drift_{\angle h}=\arctan\left(\frac{drift_h}{l}\right)$$
$$drift_{\angle v}=\arctan\left(\frac{drift_v}{l}\right) \qquad (29)$$

$drift_h$=measured horizontal drift
$drift_v$=measured vertical drift
l=distance to initial crosshair position
$drift_{\angle h}$=horizontal drift angle
$drift_{\angle v}$=vertical drift angle

Plot the horizontal and vertical angular drift values versus time for each mode. Analyze the plots for trends. Over the short time periods that are operationally significant to FLIR systems, the trend will likely appear linear. The slope of the line will provide the drift rate. The difference in the drift rates between the fuselage and geostable referenced modes will be INS induced. Note that the drift rates may be self canceling. Relate the drift rates to the workload and operator attention required to maintain FLIR orientation.

4.2.8.7. Data Cards

Sample data cards are provided as card 64.

CARD NUMBER ____

LINE OF SIGHT DRIFT RATE (GROUND TEST)

[POSITION NOSE ON TO A WALL AND 30 FEET AWAY. MARK A HORIZONTAL AND A BISECTING VERTICAL LINE ON THE WALL. SELECT THE FUSELAGE REFERENCED MODE AND NFOV, PLACING THE CURSORS ON THE INTERSECTION OF THE LINES. MARK THE CROSSHAIR POINT EACH MINUTE AND MEASURE THE DRIFTS. REPEAT FOR THE GEOSTABLE MODE.]

DISTANCE TO CROSS ON WALL ____

MODE: FUSELAGE REFERENCED

TIME (MIN)	1	2	3	4	5	6	7	8	9	10
HORIZONTAL										
VERTICAL										

NOTE: GEOSTABLE

TIME (MIN)	1	2	3	4	5	6	7	8	9	10
HORIZONTAL										
VERTICAL										

Card 64: FLIR Line of Sight Drift Rate Data Cards

CARD NUMBER ____TIME _____PRIORITY L/M/H

LINE OF SIGHT DRIFT RATE (AIRBORNE TEST)

[DESCEND TO ___ FEET AGL AND SET MACH=__. HEAD INBOUND TO THE __________ TARGET USING THE FLIR IN THE FUSELAGE REFERENCED MODE FOR NAVIGATION AND LOOK FOR TARGETS OF OPPORTUNITY. ACQUIRE THE TARGET AND PLACE THE CROSSHAIRS ON TOP. UPDATE AS REQUIRED DURING A __________ MODE ATTACK. NOTE THE FREQUENCY OF FLIR UPDATES AND THE EFFECTS UPON THE OPERATOR'S WORKLOAD AND ATTENTION. REPEAT AS TIME ALLOWS.]

ATTACK MODE __________

UPDATE FREQUENCY __________

COMMENTS:

Card 64: FLIR Line of Sight Drift Rate Data Cards (Continued)

4.2.9.FLIR Resolution

4.2.9.1.Purpose

The purpose of this test is to qualitatively and quantitatively assess the cutoff spatial frequency, minimum resolvable temperature differential, airspeed versus spatial frequency response and the line of sight jitter of the FLIR.

4.2.9.2.General

The FLIR resolution quantitative test involves a combined ground and airborne procedure that dictates the measurement of four separate performance parameters simultaneously. The parameters include the cutoff spatial frequency, minimum resolvable temperature differential, line of sight jitter and airspeed versus spatial frequency response. This test procedure requires more instrumentation and ground support than any other test of this book. For this reason, a qualitative procedure, using a minimum of assets is also provided. In keeping with the stated goal of testing with a minimum of expense, instrumentation and flight time, the qualitative assessment is performed first. If problems are noted, the entire quantitative test procedure is then performed to support the qualitative assessment with measured parameters.

The ground procedure requires the use of a collimator with a heated bar target. The collimator is a device designed to make a small ground target appear to the FLIR as if it were a larger target at a much greater distance. Figure 17 [Ref. 37: p.4.49a] depicts a typical collimator/bar target combination. The assembly consists first of a temperature controlled block which can be varied in temperature from -20° to +20° centigrade at approximate steps of 0.2° centigrade. The temperature is measured by a radiometer to an accuracy of about 0.05° centigrade. In front of the temperature controlled block is placed a template of equally spaced and equal sized slots and bars. The template is made of aluminum and approximates ambient temperature. The spatial frequency response of the target is varied by placing different sized templates on the collimator. Next is a planer mirror used to fold the IR path onto the parabolic mirror. It is the nature of a parabolic mirror that light emanating from the focal point of the mirror is reflected outward along parallel lines. The template is located at the focal point of the mirror. It is this feature which makes the target appear as if it were at a great distance. The parabolic mirror directs the IR onto the FLIR reticle. The spatial frequency of the target is approximated by the equation below. [Ref. 37: pp. 4.48-4.49].

$$SF_t=\frac{FL_c}{W_{1c}} \quad (30)$$

SF_t=spatial frequency of the target
FL_c=focal length of the collimator (folded path length from target to mirror)
W_{1c}=width of one bar and one space in target template

The airborne quantitative procedure requires the use of a full size target consisting of alternating heated and non-heated panels. Figure 18 [Ref. 37: p. 4.46b] shows a sample ground target. Note that many other targets, using both active and/or passive elements, are available at various facilities.

Rather than changing the shape of the panels, the aircraft is flown towards the target to provide a change in the spatial frequency. The temperature differential of the bars is controlled within a window of from 0.5° to 10° centigrade. The temperature is then measured to about 0.05° centigrade accuracy using a radiometer. For the airborne target, the spatial frequency of the target at a given range from the target becomes: [Ref. 37: pp. 4.46-4.47].

$$SF_t=\frac{R_t}{W_{1c}} \quad (31)$$

R_t=range from the target

The range between the aircraft and the ground bar target can be supplied by one of two methods. Typically, a ground based radar is used to provide space positioning data on the test aircraft. This is then time correlated with observations made within the aircraft to determine range to the target at the times of interest. [Ref. 37: pp. 4.46-4.47]. This method requires extensive range radar instrumentation. An alternative, and less costly option, is available if an air to ground radar is available within the test aircraft capable of tracking the IR target. Range is derived from the radar as FLIR observations are made. The sample test procedure described below uses the range radar derived space positioning data.

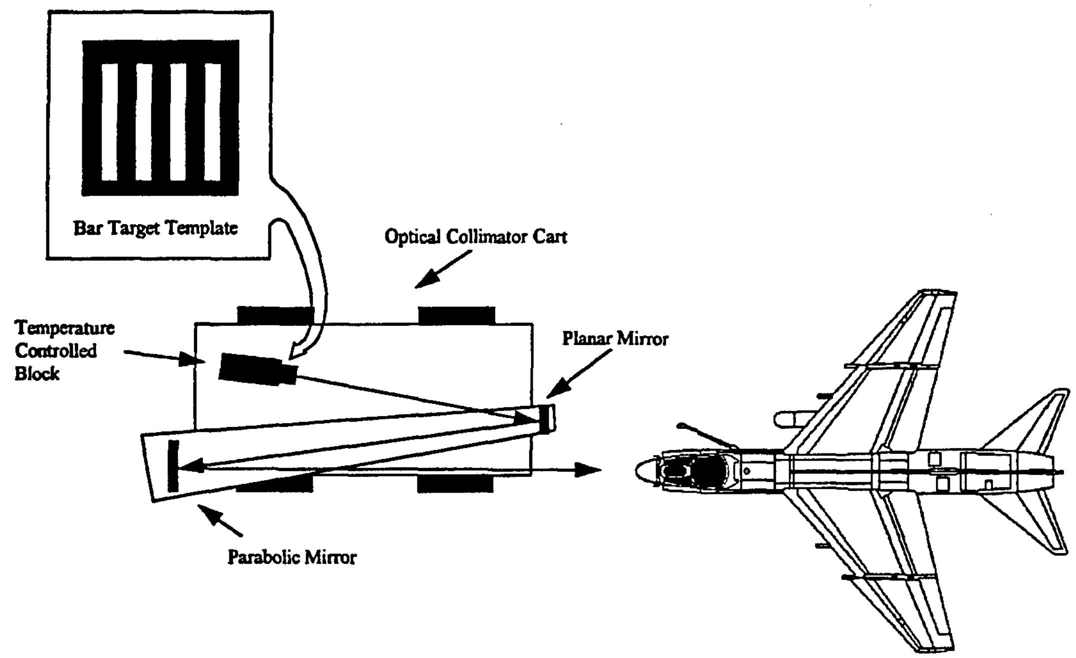


Figure 17: Typical Collimator/Bar Target Combination [Ref. 39:p.4.49a]

Minimum resolvable temperature differential (MRΔT) is the FLIR equivalent of radar minimum signal to noise ratio. MRΔT is a function of the characteristics of the target, background clutter, transmittance of the atmosphere, range to the target, characteristics of the sensor and the signal to noise necessary for desired levels of detection versus false alarms. Additionally, MRΔT is affected by less quantitized variables such as the dwell time in a scanning system, optical resolution, signal processing inaccuracies and display effects. The large number of variables, some of which are not easily measured, requires empirical testing to determine a value for MRΔT. [Ref. 37: pp. 3.15-3.19].

The cutoff spatial frequency is a measure of the angular resolution of the FLIR. Real FLIR cutoff spatial frequencies are limited by a number of effects including optical aberrations, diffraction effects, the detection element field of view, electronic effects and display limitations. These effects are present during ground testing with a stationary FLIR. [Ref. 37: pp. 3.22-3.23]. Additionally, LOS jitter affects the cutoff spatial frequency of an airborne FLIR and is caused by airframe vibrations and other sources of LOS instabilities. [Ref. 37: p. 3.24]. LOS jitter effects can thus be measured indirectly by determining the cutoff spatial frequency on the ground and then in the air and comparing the two. Figure 19 [Ref. 37: p. 4.28b] is an empirically derived plot of ground

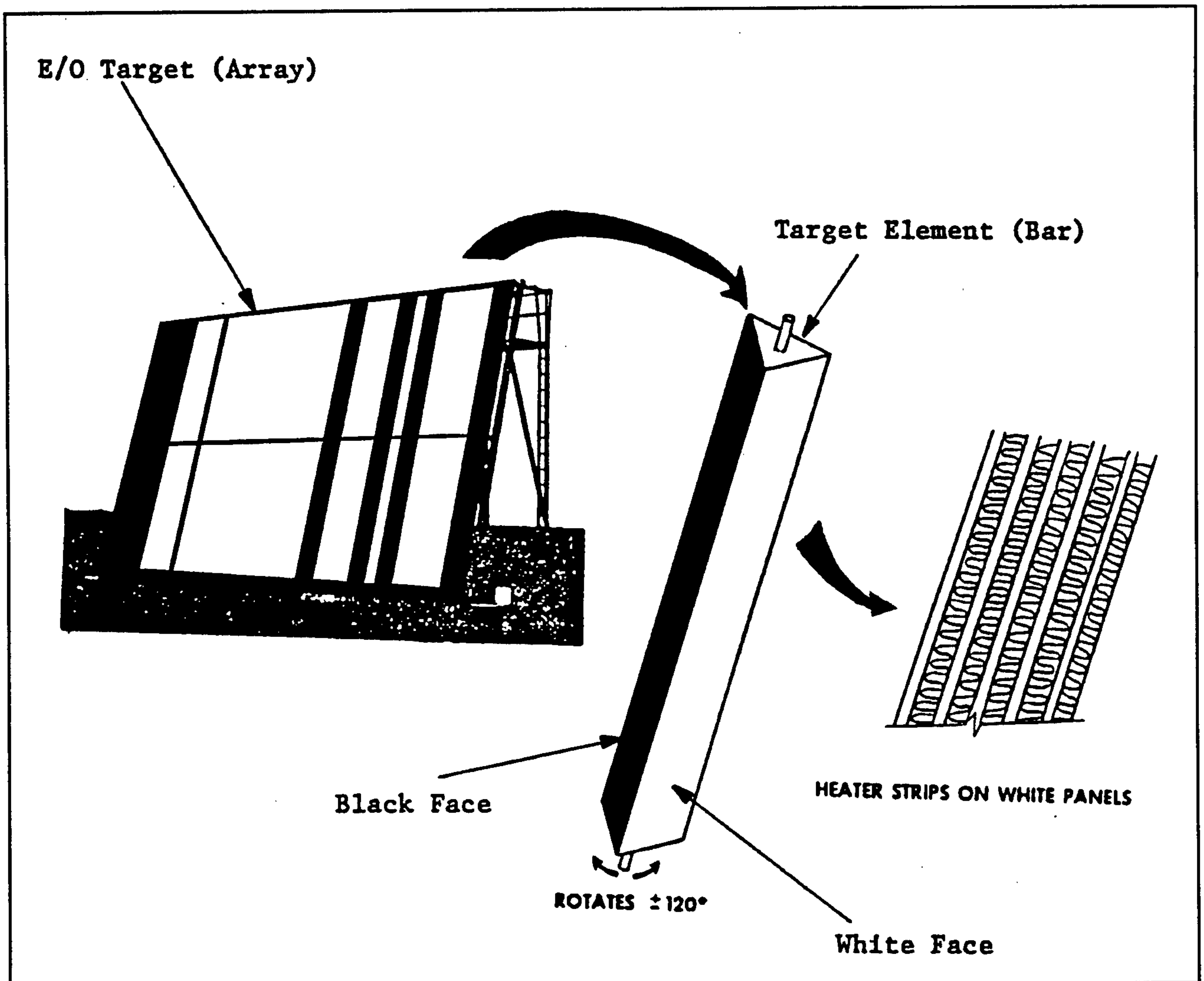
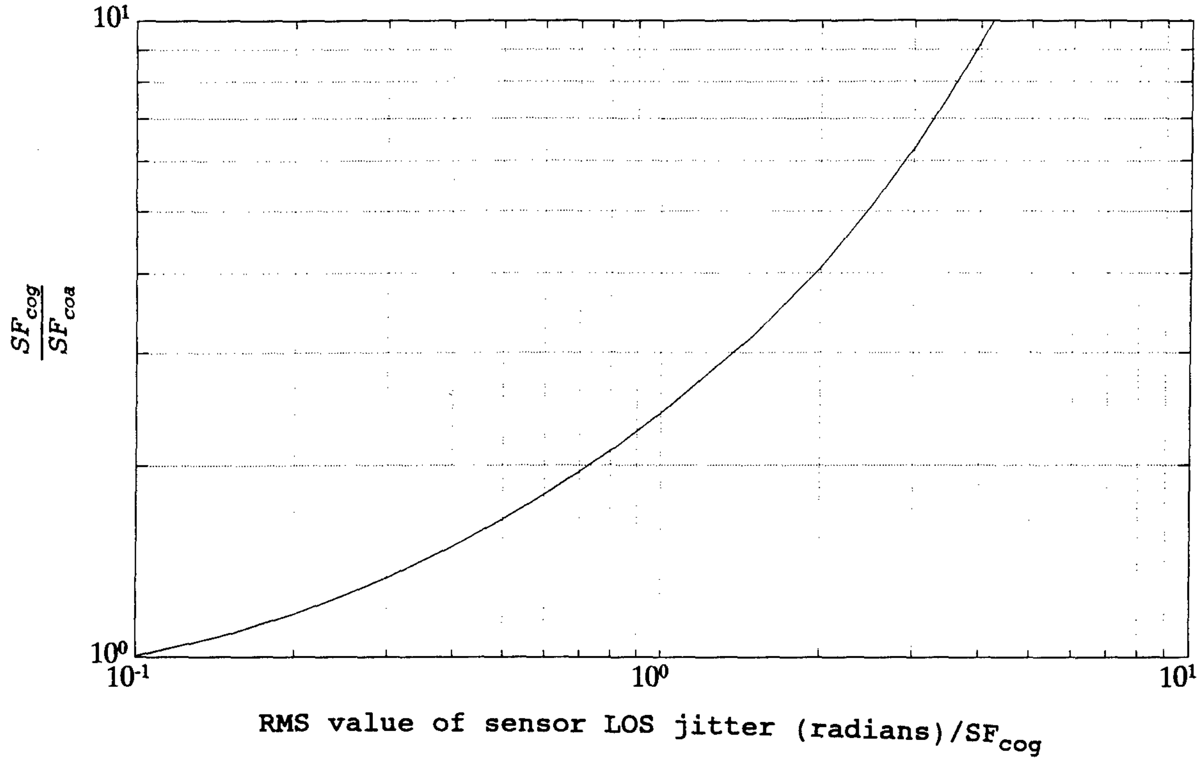


Figure 18: Sample Heated Ground Bar Target [Ref. 37: p.4.46b]

divided by airborne cutoff spatial frequency versus the root mean square (rms) value of the LOS jitter. [Ref. 37: p. 4.28b].

One important complication of the measurement of cutoff spatial frequency should be discussed. Three situations will be used as examples. In the first case, the target has a spatial frequency much lower than the cutoff spatial frequency of the FLIR. As the FLIR scans the bar target, the FLIR sees the hot and the cold bars with only short periods where the IFOV covers both. The response is shown in figure 20 part a. In the next case, the target spatial frequency is equal to the FLIR cutoff spatial frequency. In this case, the response, as shown in figure 20 part b is flat since the IFOV covers equal amounts of hot and cold bars. The third case is not as intuitively obvious. In this case, the target spatial frequency is slightly higher than the cutoff spatial frequency. As the FLIR scans over a cold bar, the FLIR sees the cold bar and in addition more than half of the hot bars on either side. The net effect is that the total appears hotter than the average of the hot and cold bars and the operator is shown the conflicting scene of hot bars where cold bars should be and cold where hot should be. Additionally, the apparent number of bars will be reduced. These effects are depicted in figure 20 part c and are theoretically repeated at multiples of the cutoff spatial frequency with corresponding reductions in the number of bars. Fortunately, the effect is rarely seen in application beyond the first interval. The effect is easily countered during tests by closely watching the targets and ensuring that data is taken at the first point where the response becomes level, as in figure 20 part b, and by watching the shape, polarity of the target (white or black bars) and number of bars. [Ref. 37: pp.



SF_{cog}=cutoff spatial frequency measured while airborne; includes LOS jitter (cycles/radian)
SF_{coa}=cutoff spatial frequency measured on the ground; does not include LOS jitter (cycles/radian)

Figure 19: Line of Sight Jitter [Ref. 37:p. 4.28b]

3.27-3.29b]. The test is performed in four parts. First a qualitative assessment is made of the FLIR to determine if the FLIR airborne minimum resolvable differential temperature and cutoff spatial frequency (angular resolution) are adequate for the mission. If not, the time and money must be spent to quantify the deficiencies. While on the ground, the collimator is used to determine a plot of resolvable differential temperature (RΔT) versus target spatial frequency (SF_t). The plot will by asymptotic on the vertical and horizontal axes as shown in figure 21 [Ref. 37: p. 4.28a]. The horizontal asymptote provides the ground MRΔT and the vertical asymptote provides the ground cutoff spatial frequency (SF_{∞}). During airborne testing, the airspeed versus spatial frequency response curve is first determined. A rough plot of the range when the bars become visible (not the false bars described earlier) versus airspeed can be plotted while airborne to determine the optimum airspeed. The evaluator may opt to merely use the normal ingress and attack speed for all further testing; however, in this procedure the optimum speed will be used. Next, the ground based bar target is used to determine the airborne values of RΔT versus SF_{∞}. These values are plotted coincident with the ground values as shown in figure 22 to determine airborne SF_{∞} and MRΔT. The airborne and ground MRΔT are theoretically the same. The difference in airborne and ground SF_{∞} ($SF_{\infty a}$, $SF_{\infty g}$)

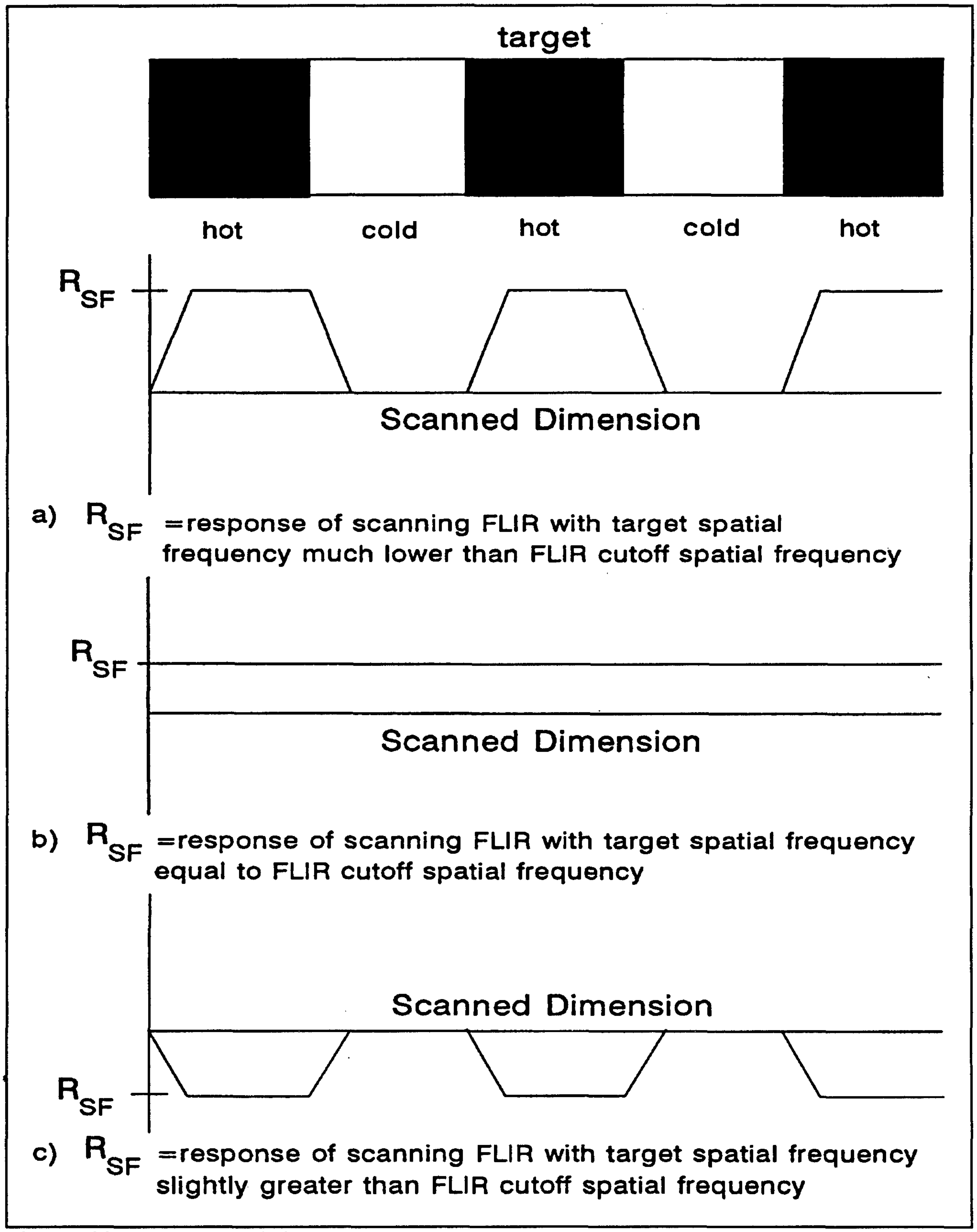


Figure 20: FLIR Spatial Frequency Response

are due to LOS jitter. As mentioned earlier, the rms value of LOS jitter is derived by entering figure 19 with the SF_{coa} and SF_{cog} values derived above. Equation 32 shows the relationship between the cutoff spatial frequency of the FLIR and the expected angular resolution. [Ref. 37: p. 4.26-4.28b].

$$r=\frac{1}{SF_{co}} \tag{32}$$

r=angular resolution of the FLIR
SF_{co}=cutoff spatial frequency

4.2.9.3.Instrumentation

Data cards and an optional voice recorder are required for the airborne qualitative portion of this test. A collimator with bar targets, radiometer, data cards and optional voice recorder are required for the ground test. A heated, ground based bar target, radiometer, ground based space positioning radar, data cards and optional voice recorder are required for the airborne range test.

4.2.9.4.Data Required

During the airborne qualitative test, record the ambient temperature, relative humidity and a complete description of any visible moisture or smoke in the test area including haze, fog, rain or clouds, along with the maximum and minimum cloud layer altitudes and visibility. Record qualitative comments concerning the visibility of objects close to the ambient temperature such as cold soaked aircraft and parked cars (static display airplanes and junk yards if you want to make sure they are cold soaked), abandoned buildings or trees. Record qualitative comments concerning the spatial resolution of hotter objects. The visibility of objects, cargo, hatches or even portholes on a steaming ship, the windows and doors on trucks or houses, even the shape of livestock in a field are possible indicators of spatial resolution (spatial frequency response). Qualitatively assess the utility of the FLIR MRΔT and spatial frequency response at a mission relatable airspeed for the assigned mission.

During the ground portion of the quantitative test, record the ambient temperature and relative humidity. Record the spatial frequency of each bar target used and the temperature differential at which the bars become indistinguishable. During the airborne portion of the quantitative test, record the ambient temperature, relative humidity and a complete description of any visible moisture or smoke in the test areas including haze, fog, rain or clouds along with the maximum and minimum cloud layer altitudes and visibility. With the target temperature set high, record the range at which the targets just become distinguishable for a range of airspeeds around the normal ingress and attack airspeeds. At the optimum airspeed, record the range at which the bars just become distinguishable, for decreasing temperature differentials.

4.2.9.5.Procedure

Prior to flying the qualitative portion of the test, select mission relatable targets near the minimum expected temperature differential. Additionally, select warmer mission relatable targets within the test area. Record the atmospheric conditions as listed above. Descend to a moderately low altitude of approximately 5,000 feet AGL and set a mission relatable ingress and attack airspeed. Qualitatively assess the utility of the FLIR for detecting and imaging the low ΔT targets and the detailed features of the warmer targets. If problems are noted during the qualitative tests perform the ground and airborne quantitative tests.

Before the ground quantitative test, record the atmospheric conditions as listed above. Check the contractor documentation and determine the theoretical cutoff spatial frequency. Select an initial bar target with a spatial frequency well below the expected cutoff spatial frequency. The spatial frequency of the targets can be determined using equation 30. Selection of the initial target and the interval for the next targets require some intuition of the expected cutoff spatial frequency and MRΔT. The technician that will undoubtedly come with the collimator may be helpful. The plot of RΔT versus spatial frequency should be plotted as the data is taken to allow feedback in the selection of bar targets. The plot should have enough data points at the correct intervals to ensure that the asymptotes and the curve are sufficiently defined. Starting at the lower spatial frequency, decrease the ΔT until the bars just become indistinguishable. Slowly raise the temperature until the bars just become distinguishable again and record the radiometer derived temperature. Ensure that the correct number of bars are present to show that the cutoff spatial frequency has not been exceeded. While data is taken, generate a rough RΔT versus spatial frequency plot and select the next bar target as described above.

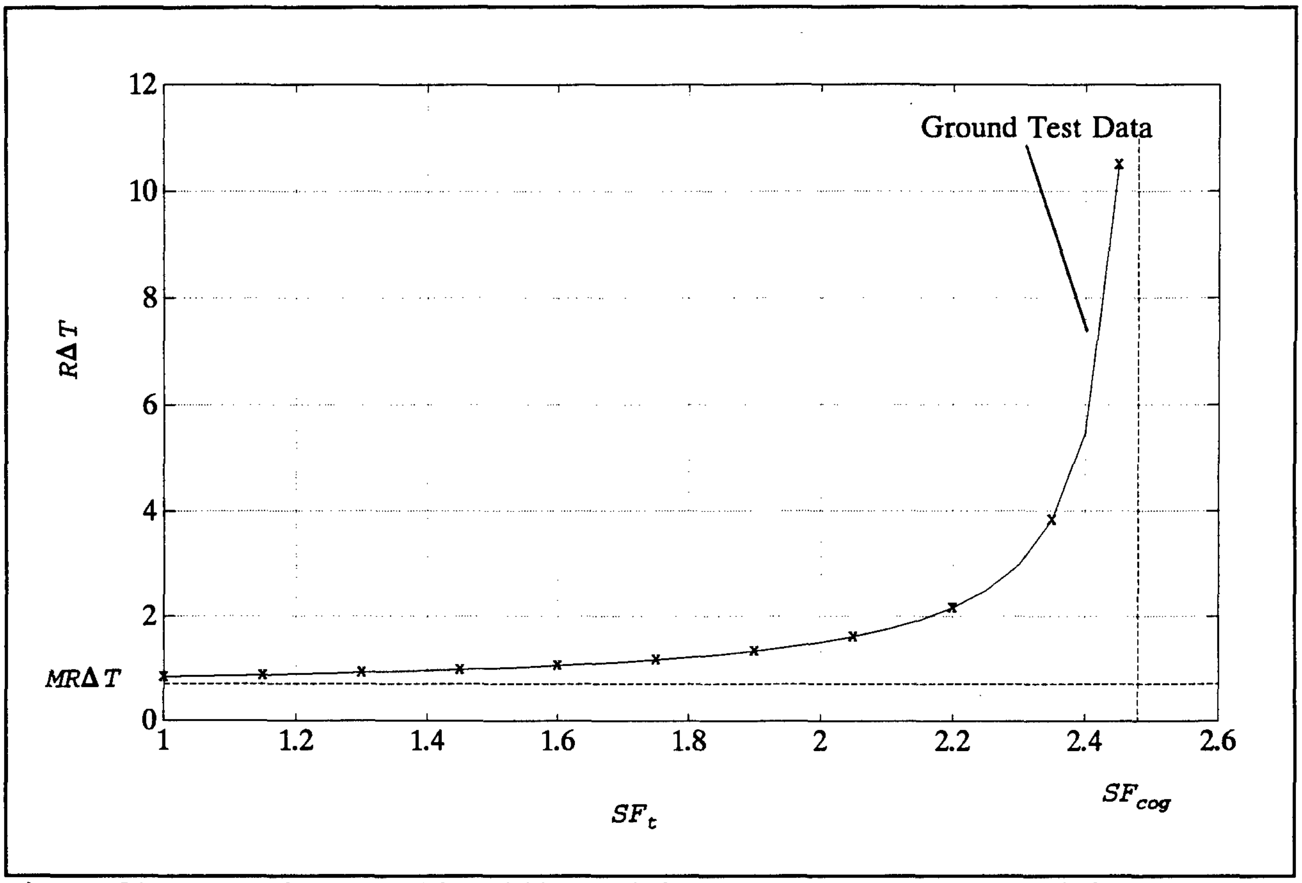


Figure 21: Ground Resolvable Differential Temperature Versus Spatial Frequency

Prior to the airborne quantitative test, record the atmospheric parameters listed above. Use the ground test data for the MRΔT value to determine a bar spacing that will allow for visibility of the target at beyond 5 nm. Choose a ΔT well above the MRΔT found during the ground testing. Choose visual cues to allow for rapid alignment with the line perpendicular to the target face at a range longer than the breakout range given the ground derived value of the cutoff spatial frequency.

Descend to the minimum altitude conducive to safe flight given the local terrain and obstruction features, the weather, performance characteristics of the airplane and qualifications of the pilot. Make the initial inbound run at an airspeed above the safe flying speed and well below the normal mission relatable ingress and attack speed. Call a mark on the radio at the point where breakout occurs and have the ground tracking engineer mark the aircraft to target range at that point. Take care to ensure that the correct number of bars are visible. Repeat at increasing airspeeds to the aircraft sealevel airspeed or Mach limit if possible and at the same ΔT and bar pattern. 50 KIAS intervals are usually sufficient. Generate a rough plot of the range versus airspeed. It may be helpful to have the ground based engineer marking the space positioning data to make the plot. The plot should peak at some airspeed value. The interval can be reduced to refine the peak value once a rough peak is found. Note that some aircraft generate a level curve. Perform the remainder of the airborne tests at an inbound airspeed equal to the peak airspeed found above or if the plot is level, at the expected mission relatable ingress and attack speeds.

During the next portion of the test, the target temperature is reduced and stabilized before each run. The data run is then made and the break-out range noted as above. A real time plot is made of the RΔT versus spatial frequency, as was done during the ground test. The plot should appear similar in shape to the ground derived plot except the vertical asymptote should be at a higher spatial frequency. The spatial frequency can be derived using equation 31. Adjust the target temperature to refine the curve and asymptotes as the

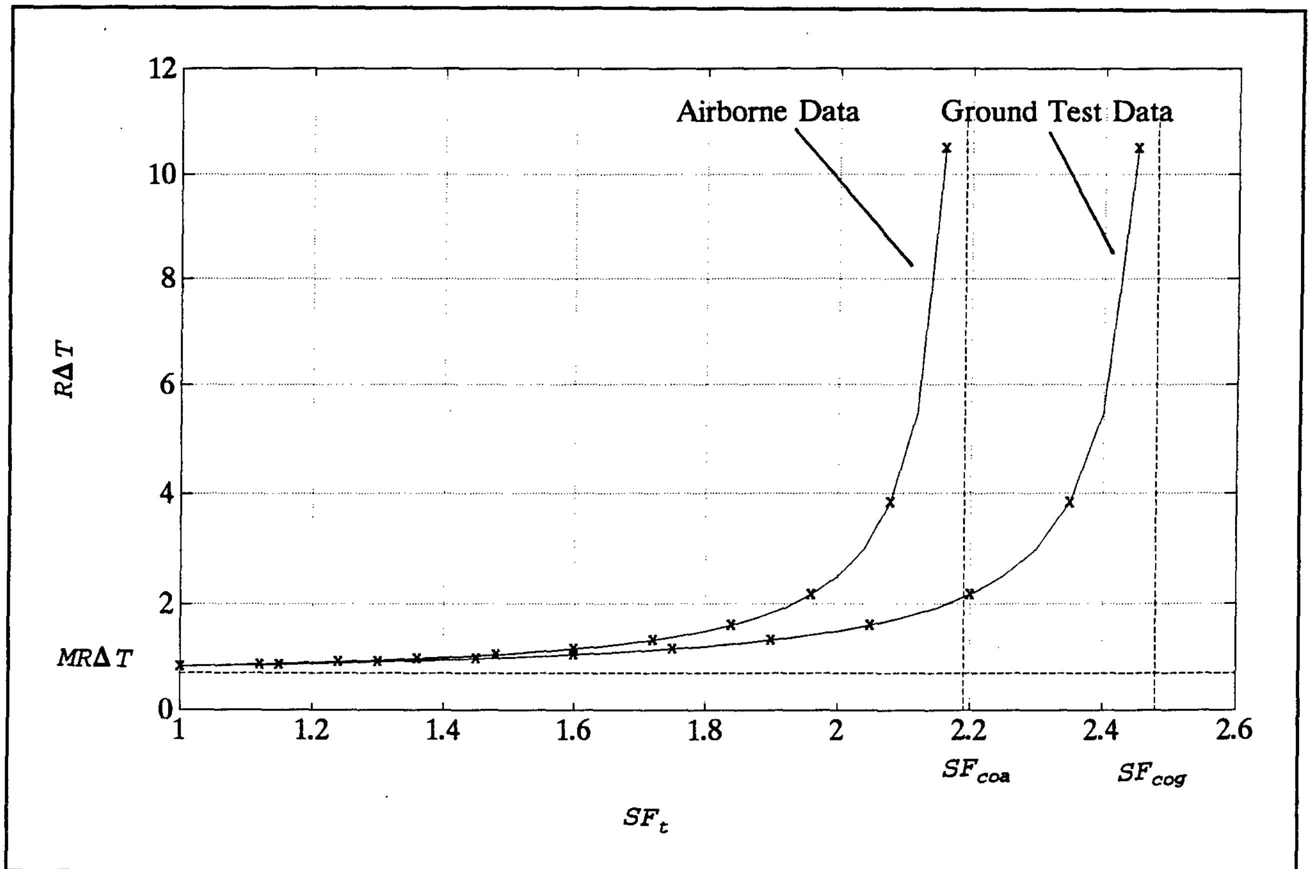


Figure 22: Airborne and Ground Resolvable Differential Temperature Versus Spatial Frequency

spatial frequency was used to refine the curve during the ground testing.

4.2.9.6. Data Analysis and Presentation

Relate the qualitative assessment of the MRΔT to the requirement to find and attack cold soaked targets of opportunity or cool operating targets. Relate the qualitative assessment of the cutoff spatial frequency to the requirement to identify small targets such as jeeps or trucks at a sufficient distance to allow set up and attack outside of shoulder fired surface to air missile range and to the requirement to view small details on targets as an aid in positive target identification in time for set up and attack outside of the expected defensive weapons range. Relate the observed atmospheric conditions to the expected mission relatable atmospheric conditions.

For the ground derived quantitative data, use equation 31 to derive the spatial frequency of the bar targets used. Plot the measured RΔT versus the spatial frequency of each target. The vertical asymptote defines the ground cutoff spatial frequency. The horizontal asymptote defines the MRΔT. For the airborne derived quantitative data, use equation 31 to derive the spatial frequency at the measured break out ranges. For the airspeed effects portion, plot the spatial frequency at breakout versus the airspeed. Relate the effects of airspeed on the FLIR spatial frequency response to the requirement to have flexibility in selecting airspeeds for navigation, ingress and attack. The optimum situation is to have a level plot over the entire range of expected operational airspeeds. The next best situation is to have the best response (the peak of the curve) over the most likely ingress and attack airspeed range. For the constant airspeed portion of the test, plot the RΔT versus the flight derived spatial frequency at breakout. Use the same plot used for the ground test results. Derive the asymptotic values of the MRΔT and airborne cutoff spatial frequency as from the ground test results. The MRΔT is theoretically identical. The airborne cutoff spatial frequency will theoretically be lower than the ground results due to jitter effects. Use the ground and flight cutoff spatial frequency results to enter figure 19 to determine the rms value of LOS jitter. Angular resolution can be derived from the ground and/or airborne cutoff spatial frequencies using equation 32. Use the results from the quantitative tests to back up the results found during the qualitative testing. Relate the observed atmospheric conditions to the expected mission relatable atmospheric conditions.

4.2.9.7.Data Cards

Sample data cards are provided as card 65.

CARD NUMBER ____TIME _____PRIORITY L/M/H

FLIR RESOLUTION (QUALITATIVE)

[DESCEND TO _____ FEET AGL, SET MACH=__. OPTIMIZE THE FLIR DISPLAY USING TARGETS OF OPPORTUNITY. SELECT THE GEOSTABILIZED REFERENCE MODE AND WHITE HOT OR COLD AS REQUIRED. RECORD QUALITATIVE COMMENTS, REPEAT AS TIME ALLOWS.]

AMBIENT TEMPERATURE _____

RELATIVE HUMIDITY _____

CLOUDS/VISIBILITY:

INITIAL POINT _______________

COOL TARGET DESCRIPTION:

QUALITATIVE COMMENTS:

INITIAL POINT _______________

COOL TARGET DESCRIPTION:

QUALITATIVE COMMENTS:

INITIAL POINT ______________

WARM TARGET DESCRIPTION:

QUALITATIVE COMMENTS:

INITIAL POINT ______________

WARM TARGET DESCRIPTION:

QUALITATIVE COMMENTS:

Card 65: FLIR Resolution Data Cards

CARD NUMBER _____

GROUND FLIR RESOLUTION (QUANTITATIVE)

AMBIENT TEMPERATURE _____

RELATIVE HUMIDITY _____

BAR SPACING	MEASURED RΔT

Card 65: FLIR Resolution Data Cards (Continued)

CARD NUMBER _____TIME _____PRIORITY L/M/H

AIRBORNE FLIR RESOLUTION AIRSPEED EFFECTS (QUANTITATIVE)

[DESCEND TO ___ FEET MSL AND SET ___ KIAS. PROCEED OVER THE IP TO THE TARGET. MARK THE BREAKOUT POINT. REPEAT AT INCREASING, 50 KIAS INTERVALS. REDUCE THE INTERVAL AS REQUIRED TO REFINE THE PEAK.]

AMBIENT TEMPERATURE _____

RELATIVE HUMIDITY _____

CLOUDS/VISIBILITY:

INITIAL POINT _______________

BAR TARGET LOCATION _______________

ΔT_____ BAR SPACING _____

AIRSPEED	RANGE

PEAK AIRSPEED _____

Card 65: FLIR Resolution Data Cards (Continued)

CARD NUMBER _____TIME _____PRIORITY L/M/H

AIRBORNE FLIR RESOLUTION AT CONSTANT AIRSPEED (QUANTITATIVE)

[DESCEND TO ___ FEET MSL AND SET ___ KIAS. PROCEED OVER THE IP TO THE TARGET. MARK THE BREAKOUT POINT. REPEAT AT DECREASING ΔT. ADJUST ΔT TO REFINE THE CURVE.]

AMBIENT TEMPERATURE _____

RELATIVE HUMIDITY _____

CLOUDS/VISIBILITY:

INITIAL POINT __________

BAR TARGET LOCATION __________

BAR SPACING _____

ΔT	RANGE

Card 65: FLIR Resolution Data Cards (Continued)

4.2.10.FLIR Maximum Range

4.2.10.1.Purpose

The purpose of this test is to determine the maximum range at which a FLIR can detect the presence of a mission relatable target and then to determine the range that the target can be identified.

4.2.10.2.General

As with radar testing, FLIR maximum range can be defined a number of different ways. For the purposes of this test, two values will be determined based upon their tactical significance to the sample system. First, the maximum range at which a mission relatable target becomes visible on the display will be determined. This range is significant since it is the maximum range at which targets of opportunity can be picked up for initial steering. WFOV is normally used in this situation and will be the test mode. Next, the maximum range at which tactically significant targets can be identified will be determined. For ships, this requires the determination of ship class and for land vehicles the type target, such as tank or truck. This range is important since in most cases it determines the range at which an attack can be committed. NFOV is normally used in this situation and will be the test mode. Since the FLIR determines bearing to the target only, an independent source of target range is required for the test. Most FLIR equipped platforms also have a radar. This will be the source of range for the sample procedure; however, if the test platform is not radar equipped, an alternate source of range truth data will be required. In most cases, this will require space positioning data on both the test aircraft and target supplied by a ground based test range radar, a costly procedure available at very limited locations.

Maximum range is dependent on five basic variables, three are functions of the FLIR design and two external to the FLIR. The three internal to the FLIR include the system optics, the detector performance and the signal processor signal to noise characteristics. These are under the control of the designer of the system and their cumulative measurement is the goal of this test. The fourth variable is the transmittance of the atmosphere and can be documented by recording the atmospheric conditions at the time of the test. Care should be taken to perform the tests during representative days. For example, performing all the tests for a FLIR designed for maritime use in northern Pacific weather, while based out of a dry desert area, would not be representative. Generally, a wide range of conditions over several flights is best. The final variable is the IR intensity of the target source. [Ref. 37: pp. 3.9-3.10]. For this test, a mission relatable target will be used and completely described within the results. This will allow the most reliable relation of the results to a realistically mission relatable environment.

4.2.10.3.Instrumentation

Data cards are required for this test, a voice recorder is optional.

4.2.10.4.Data Required

Record the temperature, relative humidity and a complete description of any visible moisture or smoke in the test area including haze, fog, rain or clouds along with the maximum and minimum cloud layer altitudes and visibility. Record the maximum range at which the target is first discernable and the maximum range at which the target can be identified. Record a complete visual description of the target. Qualitatively evaluate the level of clutter detected around the target.

4.2.10.5.Procedure

Obtain the test area surface temperature, relative humidity and visibility along with the type of obstructions to visibility from the local weather office. Record any visible moisture such as rain, fog or clouds noted along the sensor line of sight during the test. Choose a charted, mission relatable target, or visually find a target and fly outbound until FLIR contact is lost. Turn inbound to the chosen target and detect it on radar. Fly inbound until the target is first broken out on the FLIR display at WFOV. Note the radar derived range. Switch to NFOV, updating the cursor placement as required, to maintain the target on the display. Note the radar derived range at which the target can be identified. The class of ship, type of surface vehicle (such as tank, truck or train) or type of structure (such as hangar, factory, power plant etc.) must be discernable.

Visually find the target and completely describe it, including comments as to whether the target is operating since this may be an indicator of target temperature. Qualitatively assess the level of IR clutter around the target. If possible, repeat the test during varying atmospheric conditions and for as wide a variety of mission relatable targets as possible.

4.2.10.6.Data Analysis and Presentation

Relate the test day atmospheric conditions to the conditions expected in a mission relatable scenario. Relate the type or class of target, size of target and local clutter level, to the expected mission relatable scenario. Relate the maximum detection range to the requirement to scan for targets of opportunity early enough to steer in their direction and set up for an identification and subsequent attack and to the range of detection of isolated targets given approximate targeting data. Relate the maximum identification range to the requirement to maneuver for an attack of the target after identification and to the envelope of the expected target's defensive sensors and weapons. The FLIR identification range, in most cases, should allow for identification and attack prior to the target being able to destroy the FLIR platform.

4.2.10.7.Data Cards

A sample data card is provided as card 66.

CARD NUMBER ____TIME _____PRIORITY L/M/H

FLIR MAXIMUM RANGE

[CLIMB TO _____ FEET MSL AND SET ___ KIAS. BEGIN OVERHEAD __________AND TURN TOWARD THE __________ TARGET. ACQUIRE THE TARGET ON RADAR AND STEER THE FLIR IN THE TARGET'S DIRECTION IN WFOV. WHEN THE TARGET IS FIRST DISCERNABLE, MARK THE RADAR RANGE. CONTINUE INBOUND IN NFOV. MARK THE RANGE WHEN IDENTIFICATION IS POSSIBLE. REPEAT FOR THE __________ AND __________ TARGETS.]

CLOUD LAYERS:

VISIBLE MOISTURE:

TEMPERATURE __________

RELATIVE HUMIDITY __________

DESCRIBE TARGET 1:

DETECTION RANGE __________

IDENTIFICATION RANGE __________

DESCRIBE TARGET 2:

DETECTION RANGE __________

IDENTIFICATION RANGE __________

DESCRIBE TARGET 3:

DETECTION RANGE __________

IDENTIFICATION RANGE __________

Card 66: FLIR Maximum Range Data Card

4.2.11. Mission Utility and Integration

4.2.11.1. Purpose

The purpose of this test is to qualitatively assess the overall utility of the FLIR for the assigned mission and the integration and compatibility of the FLIR performance parameters, controls and display within the airplane.

4.2.11.2. General

The mission utility and integration test is the most important of the series. During this test, mission relatable ingresses and attacks will be performed to qualitatively assess the FLIR. The quantitative assessments of the previous tests will be used to back up and justify the qualitative determinations made during the ingresses and attacks. Utility refers to the overall usefulness of the FLIR as it is implemented, as an aid to the mission. The FLIR parameters must match the expected operational requirements. Integration refers to the way the FLIR has been blended into the entire airborne system. From the evaluator's stand point, this characteristic is intimately tied into the area of human factors discussed in the radar theory section. Integration is particularly important to the FLIR. Due to the inherent shorter ranges of FLIRs, the integration must be sufficient to ensure quick and effective radar or navigation handoffs to the FLIR. The EO system's inherent angular accuracy can then be used to complement the other aircraft systems during terminal phases of attack.

Additionally, the FLIRs "picture like" display makes it a natural adjunct for navigation and detection of targets of opportunity. Integration between the aircraft navigation system, attack radar and guided weapons is necessary in this case.

The qualitative assessments in mission relatable scenarios specifically called for in previous tests will also be performed during these ingresses and attacks. Care should be taken; however, to ensure that the evaluator does not get too involved in recording qualitative comments to the detriment of watching the progress of the ingress and attack and evaluating the FLIR. A conscious effort should be made not to get too involved in looking for specifics on at least the first run to ensure that an overall qualitative assessment is made. A voice recorder can be used to make comments without distracting the evaluator from the display or the outbound run can be used to record results. Multiple runs should be performed using different radar modes and mode combinations in as many different types of attacks as possible. The most likely scenarios should be performed first and the others performed as flight time allows.

4.2.11.3. Instrumentation

Data cards are required for this test. A voice recorder is highly recommended.

4.2.11.4. Data Required

Record qualitative comments concerning the utility and integration of the FLIR. Record the effects of the parameters determined in previous tests during the ingresses and attacks as called for at the end of each test procedure.

4.2.11.5. Procedure

Select a mission relatable target in the test area that allows for a 35 to 40 nm ingress to the target location. Descend to a normal ingress and attack altitude and set an airspeed near the sea level limit of the test airplane. Head inbound to the target and select a fuselage referenced stabilization mode and WFOV for use in FLIR navigation. Perform FLIR navigation inbound (for instance following a river or ridge line to the target) and search for the target with the FLIR. Update the FLIR pointing angle as required, switching to the geostable mode as desired. Find the target and select the geostable mode and NFOV, updating the cursor placement as required. Execute an iron bomb weapon delivery. After overflight, turn outbound, returning to FLIR navigation and fly to the start point. Repeat the ingress and attack using different delivery modes and if available, different target types.

4.2.11.6. Data Analysis and Presentation

Relate the qualitative deficiencies noted to their effects upon the performance of ingresses and attacks. Note any limitations upon tactics imposed by the FLIR parameters, utility or integration. The FLIR should not be driving tactics. Use the applicable results from previous tests to support the qualitative results.

4.2.11.7. Data Cards

A sample data card is presented as card 67.

CARD NUMBER ____TIME _____PRIORITY L/M/H

FLIR MISSION UTILITY AND INTEGRATION

[DESCEND TO ___ FEET AGL AND SET MACH=__. SELECT FUSELAGE REFERENCED MODE AND WFOV. START AT __________ AND FLY INBOUND TO THE __________ TARGET, PERFORMING FLIR NAVIGATION. ACQUIRE THE TARGET AND SWITCH TO GEOSTABLE MODE AND NFOV. PERFORM A SIMULATED __________ DELIVERY. TURN OUTBOUND AND NAVIGATE BACK TO THE START POINT. REPEAT WITH THE __________ TARGET AND __________ DELIVERY.]

NOTES:

Card 67: FLIR Mission Utility and Integration Data Card

4.2.12. Introduction to Advanced Electro-Optical System Test Techniques

Most of the electro-optical test techniques presented here are inherently instrumentation and asset intensive. These requirements were discussed in the respective test sections. An attempt was still made to minimize the instrumentation requirements in these sections. On occasion, additional assets should be considered, as required. For instance, if the operator actions, BITs and system faults are available digitally, they can be recorded and analyzed as described in the Advanced Air-to-Air Radar Test Techniques section, 2.3.20.

In general, each of the tests can be better documented using a time stamped, video recording of the FLIR display. Video recording also allows the replay and analysis of the display in a more leisurely ground environment. In addition, the FLIR performance can change over the course of a flight. For instance, target temperature differentials with the ambient background will change over time due to the effects of the earth's heating and cooling. The display can be replayed and directly compared for changes. As mentioned above, operator actions can be time stamped and digitally recorded to further document each test. Many of the ground measurements are facilitated by using specially constructed grids for the various angular measurements described in the previous sections.

On occasion, a more thorough documentation and measurement of the IR characteristics of the mission relatable targets used for the airborne tests is required. This usually requires extensive, realtime measurements of the target and environmental temperatures as well as all target characteristics. Another technique is to use specially constructed and instrumented target models which precisely document the target characteristics and tend to be highly repeatable. As with all of the other tests described in this book, the judicious use of instrumentation and additional assets should be researched and considered when necessary. The appropriate, advanced reference documents described in Chapter 1 or an experienced tester should be consulted as necessary.

5.0. STORES MANAGEMENT SET TESTING

5.1. Introduction to Stores Management Set Theory

5.1.1. General

The introduction of increasingly complex air-to-air and air-to-ground weapons requires modern combat aircraft to provide a vast array of varying signal sets to enable effective employment of these weapons. This function is normally performed by a Stores Management Set (SMS) or a Fire Control Set (FCS). For simplicity, the term SMS will be used to describe all systems providing these functions. An SMS can be defined as a system which provides the necessary physical and electrical interfaces for control, normal firing and/or release and jettison of airborne stores and weapons. The SMS is a system peculiar to military aircraft as the vast majority of non-military aircraft have no capability (or requirement) to accommodate releasable stores. Although the bulk of the SMS testing must be completed during the Validation and Verification (V & V) of software, much of the work must be accomplished after installation into the intended platform. This is due to the fact that the majority of the software V & V is performed using simulations of the various aircraft subsystems, none of which will completely simulate the actual hardware once installed. Since this book specifically excludes a discussion of software testing, the remainder of this section is devoted to a treatise of the techniques for performing tests of the fully integrated SMS. Note also that this document will not discuss the test techniques associated with stores separation, aerodynamic effects, static and dynamic structures or targeting accuracy.

5.1.2. Stores Management Set Architecture

Although all combat aircraft contain some form of SMS, these systems accomplish the necessary functions in varying manners. In most modern aircraft, the SMS is a fully digital, software-driven system designed to not only provide the aforementioned functions of weapons control, but also to provide store status, inventory and configuration to the aircraft mission computer. The SMS is generally the only aircraft subsystem which is electrically linked to the onboard stores. Any other subsystem resident in the airplane must communicate to onboard stores through the SMS. With newer aircraft, incorporating data busses to transmit information throughout the avionics suite, this is a logical approach to the architecture, since it ensures that any safeguards designed to avoid inadvertent release or jettison cannot be overridden by another system.

In older aircraft, or those which require less robust systems, the SMS is often a simple system of switches and wires to provide release signals to fire a gun or operate bomb racks. The capabilities and architecture of the SMS are driven by the types of stores to be accommodated and the mission of the aircraft. The test techniques to be discussed are applicable to all SMSs, regardless of the configuration or requirements of the system.

Although each SMS will embody an architecture unique to its host aircraft, most systems will have a minimum of four basic components: (1) controls and displays, (2) a Stores Management Processor (SMP), (3) station decoders, and (4) stores or bomb racks. As the controls and displays are unique in both configuration and function, depending upon the host aircraft, they will be discussed in depth later. Noticeably absent from the list of SMS components are the power supplies for each component. It should suffice to mention that all electrical devices and processors require some sort of energy to function and SMS components are not unique in this manner.

The SMP is the heart of the SMS and receives information from the aircrew via a mission computer, armament control panel, or switch position, as to the desired store type or station to be controlled or released, the release quantity and interval, and/or the mode of the store. In aircraft which incorporate a data bus architecture, the SMP is generally the sole component of the SMS to communicate on the avionics bus. Accordingly, it serves as the only means of passing information from the aircraft to the stores loaded onboard. The SMP controls the release of stores by sending coded signals to each station in the proper sequence and at the proper interval for the desired release. These signals are coded in either the time and/or frequency domain and serve as an added safety measure to effectively eliminate the ability of a simple short or electromagnetic incompatibility to cause inadvertent release of a store. The SMP also ensures that the proper signal set is sent to each weapons station in accordance with the store loaded on that station. These signals could range from a query to determine the level of fuel in an external tank to the two way communication necessary to prepare, fire and guide a fiber optic link missile.

The decoders are switches which provide the necessary voltage to the Cartridge Actuated Devices (CADs) in each bomb rack to release the loaded store. There are two decoder architectures that are used or accommodate this function. In one method, each decoder is connected to the SMP by a separate wire or wire bundle. Although this method is very simple, it requires the use of several signal paths and many wires to achieve the desired level of redundancy to ensure store release upon command. The second method is to place each of the decoders on a data bus and communicate with them using address labeled codes. Upon receiving the proper code, the decoder energizes the CADs, which in turn results in store release. Because of the amount of energy required to fire the CADs in a timely fashion, the decoder will normally draw the required current from a high energy electrical bus. In some aircraft all control commands are also sent to the loaded store via the decoder. In these cases, however, the decoder serves only as a conduit for the signal and does not normally perform any switching functions.

The bomb racks provide the structural interface between the aircraft and the loaded store. These devices are generally designed with one or more hooks which attach to the lugs of the loaded store. The racks also have one or more ejector feet designed to push the store away from the airplane at release. Most racks are gas operated, in that the CADs, once fired, provide high pressure gas which is used to open the hooks and provide energy to extend the ejector feet, thus releasing the store. Most racks also incorporate safety features, such as locking mechanisms, which physically prohibit store release regardless of whether the CADs fire or not, and auxiliary CADs which are designed to open the hooks (but not operate the ejector feet) in the event that the normal release method fails to function. The auxiliary mode is normally designed for emergency situations.

Other features which may be found on bomb racks are positive arm latches, bail bars, arming solenoids and electrical arming receptacles. Positive Arm Latches (PALs) and bail bars are designed to provide secure hook-up points for arming wires and umbilical retaining lanyards. Although the PAL will normally only perform the former function, it is not uncommon for a bail bar to perform either function. Arming solenoids are designed to hold or release arming wires to provide the capability for armed or safe release of weapons, respectively. The electrical arming receptacle is designed to provide weapons incorporating electrical fuzes, normally general purpose bombs, with an electric pulse at release to establish the mode in which the fuse will operate. Figure 23 depicts a block diagram of a generic SMS.

5.1.3. Controls and Displays

The controls and displays of the SMS are designed considering the number of aircrew operating the platform and the required interfaces for the types of stores to be employed. In general, control and display requirements are divided into the following categories: SMS BIT, store inventory and status, store selection, weapons solution display, store control, safe and arm, and release/fire consent. The first four functions are requirements accomplished through the use of multifunction or heads-up displays and keyboards in most modern aircraft. The last three functions are usually performed through the use of cockpit or aircrew accessible switches, with at least one of them being guarded to provide an extra measure of safety.

BIT is normally automatic with provisions for manual initiation. Because a failure of the SMS can lead to potentially catastrophic consequences, it is paramount that this function be extremely reliable. Not only should the BIT check the integrity of the SMS itself, but also the health of the stores loaded onboard the airplane. The BIT should ascertain to what degree the system loaded stores are usable, and clearly communicate this information to the aircrew.

Store inventory may be accomplished in one of two methods: (1) the aircrew or

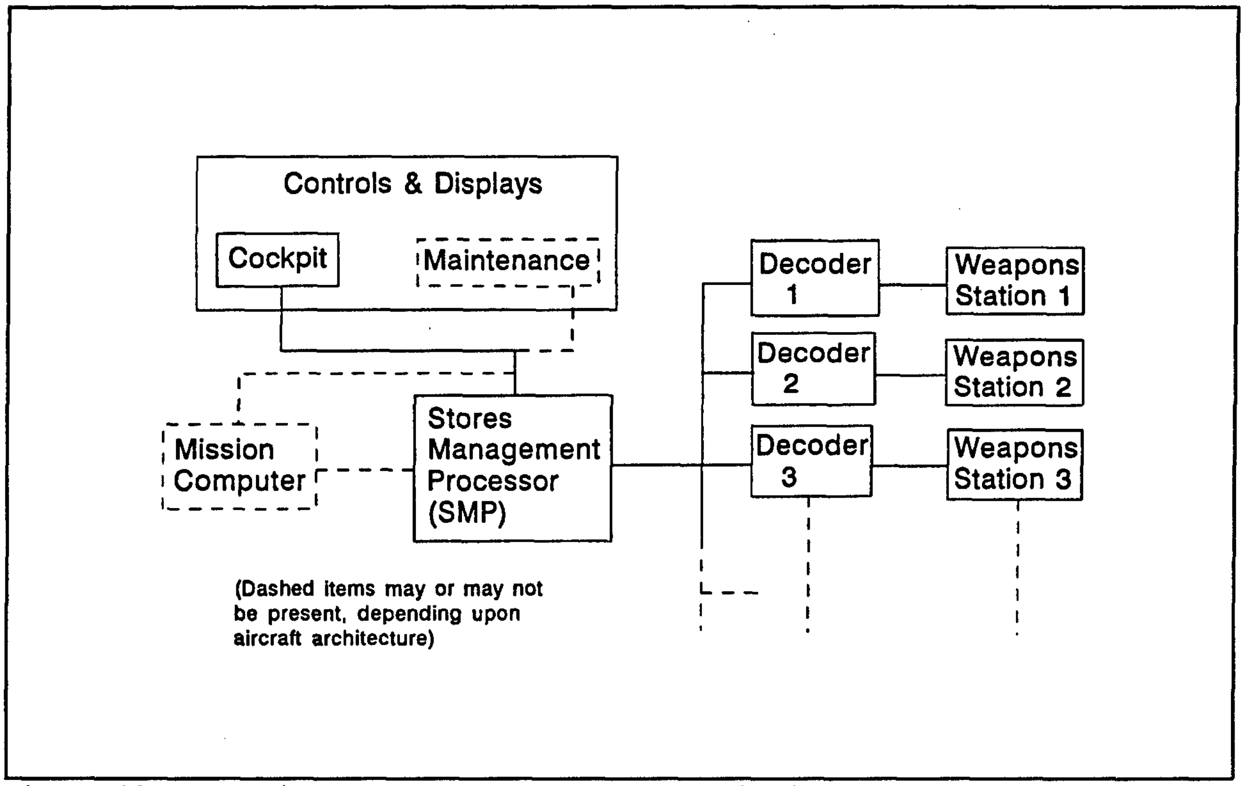


Figure 23: Generic Stores Management Set Block Diagram

maintenance personnel may "tell" the SMS what store is loaded, or (2) the SMS will query the store to identify itself. The former method is generally necessary for weapons that are unable to communicate with the SMS, such as general purpose bombs, cluster munitions and other so called "dumb" weapons. Smart weapons used to communicate with the airplane, such as guided missiles, may employ the latter. Because it is often impossible or impractical for the SMS to determine the initial store inventory, this data is often input by maintenance personnel or the aircrew themselves via an inventory panel or display. Store status includes any report which describes the readiness of the store to be delivered or jettisoned, or whether a malfunction has occurred that will prevent the delivery of the store. For example, if a normal release of a missile is attempted and not achieved, the SMS should inform the aircrew that the missile is hung, or that a required interlock has not been met. Accordingly, if the aircrew has selected a weapon and that weapon requires a finite amount of warm-up or preparatory time, this should also be communicated to the aircrew.

Store selection is the designation of a store to be released, fired or jettisoned. If a weapon is to be employed, this is normally done through selection of a weapon type on most airplanes. For jettison, and on many older airplanes for employment, selection of the station on which the store resides is the method used. On some aircraft, a single purpose Armament Control Panel (ACP) is used to select stores for employment and/or jettison. The method used for store selection should be commensurate with the criticality of employment. For example, air-to-air weapons are often employed in a reactionary manner. Consequently, selection of air-to-air weapons should be extremely convenient. This is why most airplanes possessing an air-to air capability use the Hands-On-Throttle-And-Stick (HOTAS) philosophy, where the pilot need never remove his hands from the throttle or stick to employ an air-to-air weapon. By contrast, air-to-surface weapons are mostly employed in a planned and methodical way, allowing the aircrew sufficient time to use an ACP or an SMS page on a multi-function display.

The weapons solution display, although normally provided to the aircrew via the airplane's Mission Computer (MC), is also SMS related for it is the SMS which informs the MC as to the weapon selected. In the case of unguided munitions, such as air-to-air guns or general purpose bombs, the weapons solution normally would be a HUD cue of where the weapon(s) will impact. For many smart weapons, the SMS provides the interface that tells the aircrew whether the target has been acquired by the weapon. This display can be as simple as a marker on the HUD to inform the pilot of the direction in which the seeker head of the weapon is looking. Weapons with imaging seekers require a cockpit display of the seeker head's image to be presented to the aircrew.

Store control provides pointing commands for weapons seeker heads or podded sensor systems and is usually accomplished through a joystick or other tactile device. It might also involve a determination of the mode in which a store is released. If, for example, an air-to-air missile can be launched in two different modes, say autonomous or command guided, the SMS must provide the means to establish in which mode the missile will be released.

Safe and arm is usually accomplished through a separate switch and provides an added safety measure to prevent accidental release or firing of a weapon. This switch is normally guarded and positioned in such a way as to preclude accidental selection of the ARMED position.

Release/fire consent is usually accomplished through a button or trigger depressed by the aircrew to commit the desired weapon to the intended target. In keeping with the HOTAS philosophy, the pilot normally employs weapons with stick-mounted controls. Jettison, however, is almost always accomplished via an instrument panel mounted switch.

5.1.4. Missions

The mission of the aircraft necessarily defines the requirements of the SMS. For example, an all-weather, two seat strike fighter capable of delivering a wide range of air-to-air and air-to-ground ordnance would require a vastly different SMS than an Anti-Submarine Warfare (ASW) aircraft carrying 10 aircrew designed to deliver torpedoes and general purpose bombs from a bomb bay.

To illustrate the differences in requirements, consider the two counter-examples contrasted above. Although the physical interface between the aircraft and store, normally consisting of a rack and some sort of electrical cabling, may or may not remain the same; each store requires a specific electrical signal set for proper operation. Consequently, the SMS must be designed to provide the necessary electrical interface to "speak" with each of the stores. In the strike fighter and ASW example, the strike fighter might be required to provide signals to perform BIT on all "smart" stores, monitor fuel remaining in external tanks, accept video information from different weapons and provide electrical power for weapon operation, to name a few. The ASW aircraft may not have a requirement to perform any of these functions, but instead it might have to input initial target information to the torpedoes, such as search depth or target signature, provide safety interlocks to prevent weapons release with the bomb bay doors closed and other functions foreign to the strike fighter.

Another key element relevant to the mission, which affects the design of the SMS, is the crew size. The strike fighter is designed to perform its mission in an environment which would quickly overload the crew if the SMS were not highly automated. The modern threat environment requires the strike fighter to perform a high speed, low altitude interdiction mission with the pilot assuming duties of terrain masking/avoidance and air-to-air radar sanitization. Concurrently, the operator is assessing the electronic order of battle and surface to air threats, as well as performing target acquisition and rudimentary navigation. The SMS in this airplane must provide weapons selection with the touch of a single button, with near instantaneous feedback. The operator typically moves a cursor to overlay a cross hair on the sensor display onto the intended target, and within seconds the store is released and the airplane egresses from the target area.

Conversely, the multiplace ASW aircraft operates for extended periods of time in regions far from any counter-air threat. The entire focus of the crew is on the prosecution of the submarine, with only cursory monitoring of navigation and fuel onboard. Consequently, the SMS in the ASW airplane might be designed to require inputs from several of the aircrew to deliver a weapon. One crewmember opens the bomb bay doors. Another insures that the proper target data has been provided to the torpedo. Yet another insures that all interlocks are met before releasing the weapon. The SMS in each airplane requires a totally different level of integration and automation and must be evaluated accordingly.

5.2. Stores Management Set Test Techniques

5.2.1. Stores Management Set Integration Ground Tests

5.2.1.1. Purpose

The purpose of this test is to measure the SMS firing pulse, release interval and physical interface compatibility with the host aircraft and to assess the effects that these parameters have upon the utility of the SMS.

5.2.1.2. General

The evaluator must ensure that the SMS will provide the proper signals to each store in accordance with the requirements of the store and the desires of the aircrew. These tests provide the required data to verify that these requirements and desires are met.

5.2.1.3. Instrumentation

Test kits/weapons simulators and electrical test equipment are required. The specific equipment is chosen to suit the SMS under test and the particular stores to be carried by the airplane.

5.2.1.4. Data Required

Record the fire pulse voltage, and current and duration for each discrete signal to be provided to the station for release and motor fire. Record the time difference between the arrival of the firing pulse at each station and the cockpit initiation of release. Document comments concerning the fit of the electrical interfaces with the test equipment couplers.

5.2.1.5. Procedure

Connect the weapon test kit and the electrical test equipment to the station(s) to be tested. Ensure that all stations to be tested report a store aboard (normally, hooks closed will accomplish this). Provide the SMS with an inventory corresponding to the test kits attached to each station. Input a desired interval between releases. Select the weapons or stations to be activated and command release of those stations. Repeat for all likely station and store combinations.

5.2.1.6. Data Analysis

The voltage, current and duration of each firing pulse must be sufficient to perform the intended function, i.e., release pulses should be able to fire CADs in the bomb racks, electrical fuzing pulses should be of the correct voltage and polarity and motor fire pulses should be of sufficient energy to start the intended rocket motor. Fire pulses should be sufficient and consistent regardless of the number of stations selected. Intervals between release pulses should be in accordance with that selected in the cockpit. Release pulses should arrive ONLY at those stations selected and in the correct order in accordance with an established protocol or an order which was available for selection in the cockpit. The time from the release command to the arrival of the fire pulse at the selected station(s) should be commensurate with the mission and intended stores to be employed. All couplers should fit snugly and without undue effort. Umbilicals should mate properly when using inert stores. Relate improper weapons commands to the likelihood of a hang-fire, inadvertently activating the wrong store, or a missed target as appropriate. Relate poor coupler and umbilical fits to the possibility of damaging the connector racks or stores.

5.2.1.7. Data Cards

A sample data card is presented as card 68.

CARD NUMBER ____

INTEGRATION GROUND TEST

STORE STATION	STORE SIMULATED	VOLTAGE (V)	CURRENT (A)	PULSE LENGTH (MSEC)	TIME OF ARRIVAL (MSEC)

REMARKS:

Card 68: Integration Ground Test

5.2.2. Preflight and Built-In-Tests

5.2.2.1. Purpose

The purpose of this test is to assess the suitability of the SMS preflight and turn on procedure and the BIT to quickly and easily bring the SMS system on line and insure an operational system.

5.2.2.2. General

As airplanes become more expensive, fewer and fewer will be available to accomplish each mission, amplifying the loss of individual airplanes to inflight failures. Quick, accurate ground preflight tests are essential to determine system status while repairs can still be performed. A quick response/alert time is also important and so these checks must be expeditious and must allow the operator to prepare for the mission with a minimum of distractions. Limited airplane availability also implies the need for quick turnarounds to send the same aircraft out for successive missions. This necessitates a very short preflight and turn on procedure that can be accomplished safely and thoroughly before a hurried combat mission. SMS systems have the added requirement that the modification of the store load initialization data must be easy and quick since the modification is typically necessitated by a rapid mission driven load modification or stores failure.

5.2.2.3. Instrumentation

A stop watch, data cards and stores and/or stores test sets to simulate stores are required for this test. A voice tape recorder is optional.

5.2.2.4. Data Required

Qualitative comments, time to complete the preflight/turn on, time to complete the BIT and time to store the load initialization data is required. A record of BIT indications is required. Note the effort required to alter the store load after initialization.

5.2.2.5. Procedure

Perform a normal system preflight and turn on before each test flight using the published system check list. Note the times for SMS stores initialization, the external and internal preflights and the total system preflight time up to the ready for operate indications. Perform a preflight BIT, noting the total BIT time and indications. Note any correlation between the BIT indications and the SMSs operation. Perform a complete system check out of the failure indications. Make qualitative comments as appropriate.

5.2.2.6. Data Analysis and Presentation

The time and complexity of the preflight procedures listed in the operator's checklist and SMS turn on/timeout procedure should be related to the expected alert launch time requirements and the overall operator workload during the alert launch. The BIT times and the amount of operator interface required to perform the BIT should be assessed in the same scenario. Clarity of the BIT indications should be related to the cockpit environment. The BIT indications should be related to actual SMS degradation and verified by ground technicians. Erroneous BIT false alarms should be noted and related to the probability of unnecessarily missed sorties. The time and effort to perform a change in the store load initialization data should be related to the necessity to make real time changes in the mission and loads for the aircraft.

5.2.2.7. Data Cards

Sample data cards are presented as cards 69 and 70.

CARD NUMBER ____

PREFLIGHT/TURN ON

CLARITY OF CHECKLIST INSTRUCTIONS:

LOGICAL SEQUENCE OF CHECKLIST:

THOROUGHNESS OF CHECKLIST:

SYSTEM STATUS/SMS TIMEOUT COMPLETE INDICATIONS:

TIME TO PERFORM EXTERNAL PREFLIGHT OF SMS _______________

TIME TO PERFORM INTERNAL PREFLIGHT OF SMS _______________

TIME TO STORE LOAD INITIALIZATION DATA ________________

TOTAL PREFLIGHT TIME INCLUDING TIMEOUT_________________

TIME TO MODIFY STORE LOAD INITIALIZATION DATA _________________

EFFORT TO CHANGE STORE LOAD INITIALIZATION DATA:

Card 69: Preflight/Turn On Data Card

CARD NUMBER ____

BUILT IN TESTS

INITIATION PROCEDURES:

RUN/FINISH INDICATIONS:

TIME TO PERFORM SMS BIT ________________

BIT FAILURES AND QUALITATIVE FUNCTIONAL ASSESSMENT OF SMS/RESULTS OF GROUND MAINTENANCE CHECKS:

Card 70: Built In Tests Data Card

5.2.3. Controls and Displays

5.2.3.1. Purpose

The purpose of this test is to assess the suitability and utility of the SMS controls and displays for the assigned mission as an interface between the operator and the aircraft stores.

5.2.3.2. General[16]

The controls and displays must be usable in every conceivable flight regime, ambient lighting condition, weather condition, and by aviators with the range of anthropometric measurements for which the system was designed to operate. For the modern fighter or attack airplane this is usually all weather, day or night, around +9 to -4 gs, for the 3 to 98 percentile groups, and in a realistic tactical environment filled with urgent decisions demanding the aviator's attention. For this reason, the controls and display should require an absolute minimum of operator input or interpretation and the information imparted and required from the operator should be a minimum and precisely what the aviator needs to execute the current phase of flight.

The SMS is typically required at the very peak of the pilot workload. The SMS is used just at weapons delivery, when both the defensive and offensive requirements are at a maximum, and during emergencies when stores have to be quickly jettisoned. For this reason, it is preferable to perform SMS setup and optimization on the ground at engine start or during a relatively low workload portion of the flight.

Controls should be easily manipulated wearing the proper flight clothing. The range of control (both the physical range of movement of the knob, dial, lever, etc. and the range of effect that the control has on the SMS) and sensitivity should be compatible with the expected flight regime. Controls that require manipulation while airborne should be reachable from the DEP, particularly if they must be activated in a combat environment. As an example, the chaff and flare controls must be reachable while performing high g maneuvers and while maintaining a body position ready for safe ejection. The operative sense must be correct. The direction of activation should conform to the standards of common sense (turn the knob to the right to turn on the system) and to the standards set in references 13 and 14 (which for the most part merely put on paper the standards of common sense). The operation of the controls should be clear, requiring a minimum of operator concentration and attention. This leaves the operator free to make tactical decisions. The controls should also be placed in logical functional groups, reducing the area of scan required to check the SMS set up.

The SMS controls should be integrated well into the cockpit. Correct integration requires that the controls should operate harmoniously with the other controls within the cockpit and without hindering the simultaneous operation of other airplane systems. Integration must be evaluated during a mission relatable workload and while simultaneously operating all the other airplane systems. Typically, the majority of the SMS manipulations should be performed before the workload for the mission peaks to allow real-time use of the other systems.

Lastly, the controls should provide good tactile feedback. For example, detents should provide the proper amount of "click" and all the knobs shouldn't feel exactly alike when reaching for a control with the pilot's attention elsewhere. Applying a little common sense and manipulating the controls in a mission relatable environment usually uncovers most of the control human factors violations.

The SMS status displays should be clearly visible from the DEP in bright daylight as well as complete darkness. In bright daylight, the display must be usable under all conditions of glare, including sunlight directly over the operator's shoulder onto the display (a particularly serious problem for most displays). In the dark, the display should not be so bright that it distracts the operator or affects his or her night vision. A good range of

[16]For an introduction into controls and displays human factors, see references 20, 54 and 73.

brightness control that integrates harmoniously with the rest of the cockpit is required.

The display resolution must be adequate. The display must refresh itself quick enough so that the symbology, alphanumerics and video present an even and continuous display without noticeable flicker. There should be no visible delay between the update of the SMS data and the update of the symbology, graphics and alphanumerics. For example, the display should update rapidly following operator inputs or after stores are launched or jettisoned, reflecting the new status.

Alphanumerics must be clear and legible. The messages should be short and easily understood without excessive coding or operator interpretation. The information displayed to the operator including graphics, symbols and alphanumerics must be sufficient for the current phase of flight while at the same time not overloading the operator with information. This usually requires tailoring the display to the specific attack mode/mission/phase of flight, that is currently being used. The display should be assessed for the information load in a mission relatable scenario to determine its utility as an aid in the combat environment. The use of graphics to show loads and configurations of stores is particularly useful in SMS displays. A line drawing with recognizable stores attached to the appropriate stations provides a very compact and easily interpreted presentation.

It is unlikely that a display compatible in size, weight, power and cooling requirements with a tactical airplane will be built in the near future that has too large of a usable display face. Almost all displays are too small for the task and as such should be evaluated for size in a relatable mission environment, accounting for this element of realism.

The display should be positioned in a location suitable for the mission. As an example, an SMS display which must be manipulated in real time to select the correct mix and mode for chaff and flares should be high on the front panel or on the HUD to allow the pilot to make the selections, while at the same time minimizing the time he or she spends with his or her eyes in the cockpit and consequently away from a visual scan for the threat. As with controls, display human factors problems typically surface by applying a little common sense while using the SMS in a mission relatable scenario.

5.2.3.3. Instrumentation

A tape measure and data cards are required for this test. A voice recorder is optional.

5.2.3.4. Data Required

Record qualitative comments, the evaluator's anthropometric data and a list of personal flight gear worn. The number of display raster lines per inch should be obtained from the SMS technical manual. The usable display area should be measured. Location of the display from the DEP should be measured if a qualitative problem is noted. Record the reach length of controls that are beyond the operator's reach while seated at the DEP during any mission relatable scenario.

5.2.3.5. Procedure

Find the DEP as outlined previously. All ground and airborne tests should be performed while at this position and wearing a complete set of flight gear. Perform a system turn up, on the ground outside of the hangar, in a range of ambient lighting conditions (bright daylight to darkness which may be simulated using a canopy curtain). Manipulate all controls noting the factors discussed above. Measure the display usable area. Evaluate the display for the factors discussed above. Measure and note the position and reach length to all controls and displays that pose a visibility or reach problem from the DEP. During airborne testing, manipulate the controls and make qualitative comments during mission attacks and intercepts. Take particular note during extremes of ambient lighting for displays and during high g maneuvers for controls. Confirm the results of the ground tests while airborne. Check the extremes of control limits and sensitivity. Repeat for each test flight.

5.2.3.6. Data Analysis and Presentation

Present a table of the operator's anthropometric data and the personal flight equipment worn during the tests. Present the seat position as the number of inches from the bottom of the seat travel. Relate the sensitivity of the controls to the tactical environment in which they are to be used. Relate the accessibility, placement and grouping of the controls under mission relatable conditions. A chaff and flares mode selector must be readily accessible while scanning outside the airplane and maneuvering violently. Relate the control clarity, operative sense and tactile feedback to a multiple threat, combat scenario requiring the operator to make quick tactical decisions. If ambient lighting affects the display in any way, relate this to the limits of the possible combat environments.

The display resolution should not hinder the legibility of the graphics, symbols and alphanumerics. Relate the information load presented the operator to the combat scenario discussed above and evaluate whether the needed information is present and whether too much information is cluttering the display. This concept is closely related to the size of the display face usable area. A large display can present more information without cluttering the display and requires less concentration to read and evaluate. The refresh rate should be related to the concentration required to evaluate a flickering display. The display position should be evaluated in the context of the type of information displayed, the eye position required for using the display and the display position's effect upon the scan of other displays, instruments and the outside world.

5.2.3.7. Data Cards

Sample data cards are presented as cards 71 and 72.

CARD NUMBER ____

CONTROLS

CLARITY OF OPERATION:

ACCESSIBILITY (MEASURE REQUIRED REACH IF A PROBLEM):

OPERATIVE SENSE:

ADJUSTMENT SENSITIVITY:

RANGE OF ADJUSTMENT:

TACTILE FEEDBACK:

FUNCTIONAL LOCATION/GROUPING (SKETCH IF A PROBLEM):

INTEGRATION:

Card 71: Controls Data Card

CARD NUMBER ____

DISPLAYS

[PERFORM IN BRIGHT DAY TO DARKNESS]

LOCATION QUALITATIVE COMMENTS (MEASURE LOCATION IF A PROBLEM):

CONTRAST/BRIGHTNESS/GAIN CONTROLS (RANGE OF EFFECTIVENESS):

GLARE (BOTH FROM OUTSIDE AND INSIDE COCKPIT LIGHT SOURCES):

RASTER LINES/INCH:

USABLE DISPLAY AREA ____X____

RESOLUTION QUALITATIVE COMMENTS:

REFRESH RATE QUALITATIVE COMMENTS:

LOCATION OF SYMBOLOGY/ALPHANUMERICS/GRAPHICS:

INTERPRETATION OF SYMBOLOGY/ALPHANUMERICS/GRAPHICS:

INTEGRATION:

Card 72: Displays Data Card

5.2.4. Mission Utility and Integration

5.2.4.1. Purpose

The purpose of this test is to qualitatively assess the overall utility of the SMS for the assigned mission and the integration and compatibility of the SMS parameters, controls and display within the airplane.

5.2.4.2. General

The mission utility and integration test is the most important test of the series. During this test, mission relatable ingresses, weapons deliveries, intercepts and attacks are performed to qualitatively assess the SMS. The quantitative assessments of the previous tests are used to support and justify the qualitative determinations made during the ingresses, weapons deliveries, intercepts and attacks.

Utility refers to the overall usefulness of the SMS as it is implemented, as an aid to the mission. The SMS parameters must match the expected operational needs. Integration refers to the way the SMS has been blended into the entire airborne system. From the evaluator's standpoint this characteristic is intimately tied into the area of human factors.

The qualitative assessments in mission relatable scenarios specifically called for in the previous tests are also performed during these evaluations. Care should be taken; however, to ensure that the evaluator does not get too involved in recording qualitative comments to the detriment of watching the progress of the intercept and evaluating the SMS. A conscious effort should be made not to get too involved in looking for specifics on at least the first run to ensure that an overall qualitative assessment can be made. A voice recorder can be used to make comments without distracting the evaluator from the performance of the run or the outbound run can be used to record results.

Multiple runs should be performed using different SMS selections in as many different types of attacks as possible (including supersonic runs, if applicable, to assess the utility of the SMS in highly time critical attacks and intercepts). The most likely scenarios should be performed first and others performed as flight time allows.

5.2.4.3. Instrumentation

Data cards are required for this test. A voice recorder is highly recommended.

5.2.4.4. Data Required

Record qualitative comments concerning the utility and integration of the SMS. Record the effects of the parameters determined in previous tests during the intercepts and attacks as called for at the end of each test procedure.

5.2.4.5. Procedure

For the air-to-air portion of the evaluation, place the target beyond the maximum detection range for the radar for the mode being used. Place the target 1,000 feet above the test airplane for the first run. Use the most likely, long range intercept mode for the first run and the rest in order of priority as time allows. Use a medium to wide scan angle limit and a long range scale with a two to four bar pattern to simulate a search for an inbound threat. Call for the target to turn inbound and turn the test airplane towards the target. Use a mission relatable subsonic intercept speed for the first run (usually Mach (M) 0.85 to 0.9 for both the target and test airplane is adequate). It is important to use enough speed, since the closure rate will affect the evaluation of the SMS and the workload required to select and deliver weapons. Perform a normal intercept, optimizing the range scale, scan angle limits, antenna elevation angle etc. until the target is confirmed and an STT is acquired. Select and perform a simulated launch of the long range, medium range and short range front profile weapons as the launch envelope for each is reached. Continue inbound and convert the intercept to an astern attack of the target as the target continues to fly straight and level. Use the ACM modes during the conversion and simulate the selection and firing of weapons, paying particular attention to the required workload upon the tactics used for each weapon.

If two targets are available, use them both on at least one intercept and then split them onto two stations, switching from one to the other (three in a barrel) to maximize the number of intercepts during the flight. If time, fuel and airspace permit, perform one supersonic intercept to minimize the time available to make the required manipulations of the SMS. If time permits, allow the target to maneuver up to 30° and 5,000 feet (excluding 1,000 above or below the test airplane altitude) off of the planned track without informing the evaluator of the maneuver beforehand, to simulate a moderately "jinking" target. Record qualitative comments concerning the utility of the SMS for the assigned mission, including the effects of the parameters determined during previous tests and the overall integration of the SMS into the airplane.

For the air-to-ground portion of the evaluation select a mission relatable target in the test area that allows for a 35 to 40 nm ingress to the target location. Descend to a low ingress altitude and set an airspeed which would normally be selected for an attack of a defended target. Head inbound to the target and select a radar mapping mode with at least a 40 nm scale and a wide scan pattern useful for radar navigation. Perform radar navigation inbound to the target (for instance following a river or ridge line that leads to the target) and search for the target on the display. Perform simulated deliveries of stand-off weapons. Continue to update the antenna elevation angle, display range and antenna pointing angle to optimize the display for navigation and target search. When the target breaks out, select the DBS modes and continue to update the target position. Execute the type weapon delivery most likely for the test airplane and the type of target selected. Turn outbound, selecting a mapping mode and navigate outbound from the target area to the start point. Repeat the ingress and attack using different delivery modes, weapons and if available, different target types.

5.2.4.6. Data Analysis and Presentation

Relate the qualitative deficiencies noted to their effects upon the performance of the ingresses, weapons deliveries, intercepts and astern conversions. Note any limitations upon tactics imposed by the SMS parameters, utility or integration. Use the applicable results from the previous tests to support the qualitative results.

5.2.4.7. Data Cards

Sample data cards are presented as cards 73 and 74.

CARD NUMBER TIME ____ PRIORITY L/M/H

SMS AIR-TO-AIR MISSION UTILITY AND INTEGRATION

[POSITION THE TARGET ON THE NOSE AT ___ NM AND 1,000 FEET ABOVE THE TEST AIRPLANE. TURN THE TARGET AND TEST AIRPLANE TOWARDS EACH OTHER, ACCELERATING TO M=__. USE THE ____ MODE, WIDE SCAN ANGLE LIMIT, ____BAR PATTERN, AND ____ NM RANGE SCALE. GAIN AN STT AND CONTINUE INBOUND. SIMULATE A LONG RANGE MISSILE LAUNCH, A MEDIUM RANGE HEAD-ON SHOT THEN A SHORT RANGE HEAD-ON SHOT. OFFSET THE TARGET AT 10 NM AND PERFORM AN ASTERN CONVERSION. USE THE ACM MODES DURING THE CONVERSION. SIMULATE ASTERN MISSILE AND GUN ATTACKS. MAKE NOTES CONCERNING THE MISSION UTILITY, INTEGRATION AND THE EFFECTS OF SMS PARAMETERS. REPEAT WITH THE TARGET AT ___ FEET AGL. REPEAT THE TEST WITH THE TARGET AND TEST AIRPLANE AT M=___.]

NOTES:

Card 73: SMS Air-To-Air Mission Utility And Integration Data Card

CARD NUMBER ____ TIME ___ PRIORITY L/M/H

SMS AIR-TO-GROUND MISSION UTILITY AND INTEGRATION

[DESCEND TO ___ FEET AGL AND SET MACH=___. SELECT THE MAP MODE, ___ NM RANGE SCALE AND THE __° SCAN ANGLE LIMIT. START AT ________________ AND FLY INBOUND TO THE _________________ TARGET AT AN INITIAL HEADING OF ___. RADAR NAVIGATE TOWARD THE TARGET AREA AND WHEN IN CONTACT WITH THE TARGET SELECT DBS. PERFORM A SIMULATED ____________ STAND OFF WEAPON DELIVERY, THEN PERFORM A SIMULATED ____________ WEAPON DELIVERY. TURN OUTBOUND AND NAVIGATE BACK TO THE START POINT. REPEAT WITH DIFFERENT DELIVERIES AND TARGETS.]

NOTES:

Card 74: SMS Air-To-Ground Mission Utility and Integration Data Card

5.2.5. Introduction to Advanced Stores Management Set Test Techniques

As mentioned in Chapter 1, only the most rudimentary form of the Stores Management Set test techniques are presented in this book. Chapter 1 details the reasons for this format; however, in many applications, more rigor, accuracy and documentation of results are required. Table VII outlines additional instrumentation and assets which are typically applied in these more advanced tests. The purpose of this table is merely to emphasize the existence of these advanced techniques. Further, this list is not exhaustive. Many innovative uses of assets and instrumentation exist. It is hoped that the examples provided leave the reader with a taste of how the test can be made more rigorous through the judicious use of instrumentation. In application; the user must refer to the more advanced documents referenced in Chapter 1 or solicit help from more experienced testers.

Table VII: Additional Assets or Instrumentation for use in Advanced Stores Management Set Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Stores Management Set Integration Ground Tests.	Digital Recorder. Video recording of operator actions and stores stations.	If a data bus is used in the stores management architecture, the time stamped bus activity is recorded in order to compare to the actual electrical signals sent to each station as the tests are performed. Digital data exchanged between the Stores Management Set (SMS) and the stores on each station are recorded. Time stamped video is made of the operator actions and displays for correlation with the time stamped bus activity. Video is made of the activity on each station in order to document coupler and umbilical deficiencies.
Preflight and Built-in-Tests.	Digital Recorder.	Typically records data from the data bus on which Stores Management Set passes the BIT results and receives results from the stores stations. Allows precise documentation of test results. Usually used in conjunction with fault insertion tests.
	Video recording of display.	Provides automatic recording of what the operator sees as the fault status is displayed.
Controls and Displays.	Video recording of display.	Allows automatic documentation of display problems as well as post-flight analysis and evaluation.
	Cockpit mock-ups, reconfigurable cockpits and virtual cockpits.	Typically used for in-depth ground tests of human factors and in iterative cockpit design.
	Digital recording of operator actions.	Can be used as a means of precisely recording operator selections to document noted problems and as a means of performing operator tasking analysis.

Table VII:Additional Assets or Instrumentation for use in Advanced Stores Management Set Tests

Test	Additional Asset or Instrumentation	Purpose/Benefit
Mission Utility and Integration.	Same as in the Stores Management Set Integration Ground Tests.	This test requires the largest amount of data to completely document the results. It is during this test that most of the unexpected problems are found. In anticipation of having to document these deficiencies, maximum instrumentation are sometimes brought to bear for this test in case unforseen data are required in post-flight analysis.

6.0. FLIGHT PLANNING

As has been mentioned, many of the tests can be conducted concurrently, or at least on the same intercept, ingress or attack. In addition, some of the tests will be more important than others. Past performance of the system, the specific system design, and ground test results will point out the areas that require emphasis. Finally, climbs/descents, accelerations/decelerations and positioning of targets and test airplanes requires fuel and time and must be kept to a minimum. Preflight planning is needed to insure that all the data that can be taken on each run are planned for while at the same time not overloading the evaluator. Priorities must be set for each data point so that if fuel/time run short, the most important data points have been identified and can be obtained first. A well thought out plan for the conduct of the flight will maximize the data obtained over a given flight and insure that the critical items are obtained first.

The first step in planning is to group the data points that are compatible on concurrent runs. This must be done in light of the type of run being performed, the characteristics of the specific systems under test, and airspace constraints of the test. As an example, for an air-to-air run against two targets, a search mode maximum range data point could be taken concurrent with a maximum acquisition range data point. Then, as the targets continue inbound they can maneuver for a range resolution data point, while the evaluator checks for ambiguous ranges and blind ranges.

Airspeeds and altitudes should be chosen that maximize fuel conservation without destroying the mission relation of the test. Where speed and altitude are not critical to making the test mission relatable, medium to high altitudes near the maximum endurance airspeed should be chosen. As an example, the maximum range measurements can be made at a maximum endurance airspeed since the speed used will not affect the data. Tests that require the target within 10 to 15 nm can be performed outbound to the test area or following a converted intercept. Tests should also be grouped by altitude. Usually low (below 5,000 feet AGL), medium (10,000 to 20,000 feet MSL) and high altitude (above 20,000 feet MSL) tests should be grouped together during the flight.

Navigation test flyover data points pose a particularly challenging flight planning exercise. Since the flyover method requires that the tests be performed at a very low altitude, extensive planning is warranted to group them together to preclude numerous climbs and descents. Usually it proves efficient to merely stay low for the duration of the navigation tests and to work as many other low altitude data points in as possible between flyover opportunities. Air-to-ground radar and FLIR data points are often compatible with a series of flyover data points.

After the runs have been designed, an estimate should be made of the time necessary for set up and to perform the tests. Armed with the time required for each run, a timetable of the flight can be drawn up and the maximum number of tests scheduled within the flight time and fuel constraints. The data cards should be laid out in order, numbered, and the expected time into the flight at the beginning of each test placed on the card. This allows the evaluator to have a running estimate of how effectively he or she is managing the flight time available as the flight progresses. The evaluator should also mark the low and high priority tests through some ranking scheme. The sample data cards are provided with a priority Low/Medium/High (L/M/H) selection. As time becomes a problem, as indicated by the elapsed time since launch and the time estimate on the data card, the low priority tests should be skipped in preference to the high priority tests.

There is no single way to structure the tests that will work for every situation. Common sense and an understanding of the requirements of each test will define most of the flight. Unfortunately, this portion of the test is often given a minimum of thought in deference to "figuring it out in the air." This mindset must be avoided and the flight must be laid out beforehand. A successful test will almost always result. Success is best insured by knowing the system, planning the flight and flying the plan.

Safety must also be an important criteria in preflight planning. Airspeeds, altitudes and rates of descent/climb should be chosen not only for their utility in gathering data but also for their effects upon safety. In aircraft where gross weight restricts maneuvering, tests should be laid out such that high g data points are performed after fuel is expended and the gross weight is within the required limits. The work load should be budgeted so that the evaluator has enough time available to properly perform the test and still aviate, navigate, look for traffic, etc. Ideally, the test should be performed in a dual piloted aircraft, allowing one pilot to concentrate on the test while the other flies the aircraft. With two pilots, proper crew coordination is an important safety concern.

Where airborne targets are used, a face to face brief prior to the test must be required. The procedures for each test should be understood by all participants. A procedure to immediately terminate each test whenever any participant notices any unsafe condition must be thoroughly briefed.

The test systems and safety of flight systems required for each test and target aircraft must be outlined and used as a criteria for test cancellation. It is much cheaper to cancel a test while on the ground than in the air.

Time should be set aside during the planning stage of any test for all the participants to gather and discuss the safety of flight issues. A simple but effective procedure is to reserve a short period of time (perhaps a half hour) during the planning process for all participants to discuss possible safety issues, system failure modes or accidents that could occur and to plan how to react in their eventuality. A half hour of planning is a small price to pay for a safe test evolution.

7.0. CASE STUDY

7.1. INTRODUCTION

The previous sections provided a discussion of how to perform basic flight tests on air-to-ground radar, air-to-air radar, navigation, electro-optical and stores management set systems. A basic assumption for the development of these techniques was that a minimum of instrumentation was available outside of the production aircraft's complement of systems. In implementation this is often the case. Scheduling or cost may limit the amount of instrumentation and support available to perform a test. Additionally, as explained in Chapter 1, even when instrumentation allows extensive data collection, the test techniques are often similar or even identical and the rough, hand-held data is still collected. The data is then available for immediate use, without the requirement for extensive data reduction and formatting usually needed after automatic collection. This immediate feedback is used for adjusting of the next test evolution or as a means for focusing the data reduction effort on test events which are critical.

The following case study is presented to illustrate the implementation of the thought process used in developing the test procedures outlined in the previous sections. This case study is a straight-forward application of a couple of the test procedures outlined above without the addition of extensive instrumentation requirements. The scenario is contrived but illustrates how the techniques above can be used to provide quick and supportable answers to real world questions where extensive preparations and instrumentation are not possible.

7.2. AIR-TO-GROUND RADAR RESOLUTION USING A MINIMUM OF INSTRUMENTATION

7.2.1. Background

This case study is intended to illustrate how the techniques outlined in the previous sections may be applied to quickly answer a question about the technical performance of a radar. The scenario is based upon a fictional United States Navy F/A-XX aircraft with the APG-XX radar. The APG-XX radar has been developed as an avionics upgrade to the F/A-XX aircraft. The Navy program manager, responsible for the development and procurement of the upgrade, (PMA-XXX) has heard via his program contacts that the APG-XX radar is "not even close" to meeting the air-to-ground resolution specification. A specification is a design requirement imposed upon the contractor as a means of defining the minimum acceptable standards for the system under development. PMA-XXX called your department head and ordered a "quick test" to determine the air-to-ground range and azimuth resolution of the radar. You have been assigned as the project engineer.

The contractor has been prompted by PMA-XXX to make the back seat of the single prototype of this two seat strike fighter available tomorrow to do a quick evaluation of the air-to-ground radar resolution as a "piggy back" test on a contractor evaluation. The aircraft is currently in the custody of the contractor as the contractor engineers interactively develop the radar. The contractor has further restricted your evaluation to 30 minutes. Data cards are required so that the project test pilot can leave for the contractor facility in four hours.

As mentioned frequently in this book, an in depth knowledge of the system is essential to the development of a good test. Here, a condensed description of the radar is provided, including only those facts germane to the test design process.

7.2.2. The Test Article

The APG-XX radar has three modes of operation, including REAL BEAM MAP, DBS 1 and DBS 2. In the REAL BEAM MAP mode, the transmit pulse waveform has a pulse width of 0.764 μsec at a 40 nm range scale or less, uncompressed. In the 80 to 40 nm range scale, the pulse width is 2.29 μsec, uncompressed. The antenna beam width is 1.3° horizontally and is spoiled vertically. The display resolution is 75 pixels per inch and the range scales available include 80/40/20/10 nm with automatic downscale available as the aircraft approaches any point which is selected by the geostable cursors.

In the DBS 1 mode, the pulse width is 0.306 μsec, uncompressed at all DBS ranges. The beam width is the same as the REAL BEAM MAP mode beam width and the DBS ratio is 10. The display resolution is the same as in the REAL BEAM MAP mode and the display scale is a 10 nm by 30° B scan format. The maximum range is 40 nm in DBS 1 and the DBS notch width is 7°. In the DBS 2 mode the pulse width, beam width, DBS ratio, display resolution, DBS notch width and maximum DBS range are the same as in DBS 1. The only difference between DBS 1 and DBS 2 is that the DBS2 display is a two fold "blow up" of the DBS display making the DBS 2 display scale 5 nm by 15°.

7.2.3. Theoretical Resolution

In developing the test scenario, it is important to first bound the test parameters by the maximum theoretical limits, and therefore make best use of the test time. The theoretical azimuth and range resolution limits are thus required. The theoretical resolution may be limited by either radar performance or the display resolution. The amount of time that a radar wave requires to travel one nautical mile is defined in Chapter 2 and repeated below in equation 33. The pulse width is then used to calculate the theoretical range resolution of the radar in all three air-to-ground modes.

$$\begin{gathered}\textit{Radar Mile} = 12.36\frac{\mu\text{sec}}{nm}\\ \textit{Real Beam Map}>40nm\ \textit{Scale}:\\ (2.29\mu\text{sec})\left(12.36\frac{nm}{\mu\text{sec}}\right)\left(6000\frac{ft}{nm}\right)=1112\ ft\\ \textit{Real Beam Map}<40nm\ \textit{Scale}:\\ (0.764\mu\text{sec})\left(12.36\frac{nm}{\mu\text{sec}}\right)\left(6000\frac{ft}{nm}\right)=371\ ft\\ \textit{DBS 1 and 2 (same PW)}:\\ (0.306\mu\text{sec})\left(12.36\frac{nm}{\mu\text{sec}}\right)\left(6000\frac{ft}{nm}\right)=148ft\end{gathered} \tag{33}$$

Examining the results, it is important to note that the theoretical range resolution is independent of the range to the target; however, the aircraft must be close enough to the range resolution array targets to allow detection of the individual elements of the array. The array may actually include elements of several different radar cross sections and so the evaluator must be aware of the possibility of detecting some elements of the array at different maximum ranges independent of the range resolution characteristics of the radar under test.

Figure 24 illustrates the calculation of the theoretical azimuth resolution of the radar. The azimuth resolution is dependent upon the beam width of the radar antenna and upon the limitations of any schemes designed to improve the azimuth resolution such as in the DBS mode, as outlined in Chapter 2. Two values are significant. First, the radar angular resolution is required. For the Real Beam Mode, this value is equal to the beam width of the radar, which is 1.3°. In the DBS modes the angular resolution is equal to the beam width divided by the DBS ratio. The DBS ratio for the sample radar system is 10 for both the DBS 1 and DBS 2 modes and so the DBS 1 and 2 modes angular resolution is 0.13°. As outlined in Chapter 2, the azimuth resolution array is composed of fixed ground radar reflectors and so the angular resolution value must be interpreted in terms of distance over the ground. The most useful value is the theoretical range at which it is expected that a pair of resolution array targets of known separation will be distinguishable, or break out, as two distinct targets, defined as R_b. This value is calculated as in equation 34.

$$R_b=\frac{S}{\tan(\theta)} \tag{34}$$
R_b=*target range at breakout*
S=*across axis target separation*
θ=*angular resolution*

Figure 25 is a diagram of the fictional resolution array. The azimuth resolution targets are at the top of the T shape. The widest azimuth target separation of 600 feet in figure 26 is applied to equation 34 for the case of the Real Beam Mode and then for the DBS mode to get equation 35. Table VII shows the results of similar calculations made for all the radar modes and for the three azimuth resolution target separations of 600, 300 and 100 feet.

Real Beam Example:
$S=600\ ft,\ \theta=1.3°$
$$R_b=\frac{600\ ft}{\tan(1.3°)}\frac{1}{\left(6000\frac{ft}{nm}\right)}=4.4\ nm \tag{35}$$
DBS Example:
$\theta=1.3°$, *DBS Ratio*=10
$$R_b=\frac{600\ ft}{\tan\left(\frac{1.3°}{10}\right)}\frac{1}{\left(6000\frac{ft}{nm}\right)}=44\ nm$$

The radar design provides one set of theoretical resolution limits. The display also has resolution limits. The most restrictive of the two sets of limits is the true theoretical resolution limit for the total system. The display measures six inches across and six inches high for a total of 36 in^2. The display resolution is 75 pixels per inch in both directions. In the Real Beam Mode of operation, the possible range scales include 80, 40, 20 and 10 nm in both directions. In DBS 1, the B scan format display scale is 10 nm by 30° and in DBS 2 the scale is 5 nm by 15°. Figure 26 illustrates the implications of these values where it is noted that in theory, two targets must be separated by at least one pixel to be distinguishable on the display. In practice, more pixels of separation are typically required; however, this conservative limit suits our purposes.

Equation 36 is an example calculation for the separation over the ground of two pixels on the display for the Real Beam Mode, 80 nm range scale display. This calculation was repeated to develop the theoretical display resolution limit for all of the possible range scales assuming that the theoretical limit is imposed by the requirement that the targets be separated by at least one pixel to be broken out. The results are included in table VIII.

$$\left(\frac{80\ nm}{6\ in}\right)\left(\frac{1}{75\frac{pixels}{in}}\right)\left(6000\frac{ft}{nm}\right)=1067\frac{ft}{pixel} \tag{36}$$

Table IX includes all of the theoretical radar and display range resolution calculations and shows which is the limiting factor for the total system performance. As shown, the radar is the limiting factor for all but the case of the Real Beam Mode and the 40 nm display range. Table X repeats the comparison for the theoretical azimuth resolution. In azimuth, the radar is the theoretical limiting factor in resolution for all but the 100 feet separation target and the Real Beam Mode of operation.

As mentioned above, the theoretical resolution was calculated in order to bound the flight test requirements and save test time. Analyzing the two previous tables allows several conclusions to be drawn concerning when the azimuth and range resolution targets could first be broken out on a data run inbound to the resolution array:

In Real Beam Mode Expect:

*In Range:

✓80 to 40 nm no breakouts
✓40 to 20 nm no breakouts
✓20 to 0 nm one breakout

*In Azimuth:

✓80 to 4.4 nm no breakouts
✓4.4 to 2.2 nm two breakouts
✓2.2 to 0 nm four breakouts

In DBS 1&2 Expect:

*In Range:

✓80 to 40 nm...Not Displayed
✓40 to 0 nm two breakouts

*In Azimuth:

✓80 to 40 nm...Not Displayed
✓40 to 22 nm two breakouts
✓22 to 7.3 nm four breakouts
✓7.3 to 0 nm six breakouts in DBS 2 only, due to display resolution

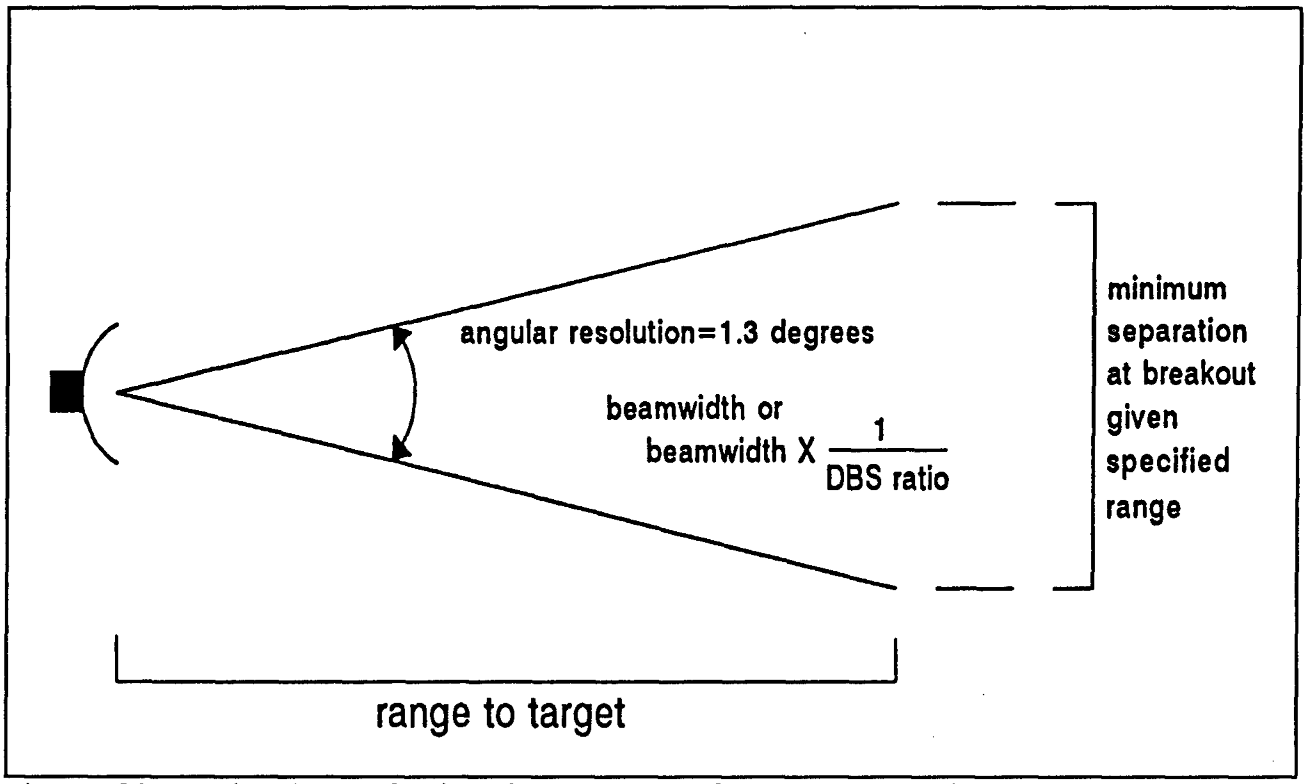


Figure 24: Azimuth Resolution for Targets of Known Separation

Table VII: Theoretical Azimuth Resolution for all Air-to-Ground Radar Modes and all Azimuth Resolution Target Separations

Target Separation	Real Beam Breakout	DBS 1&2 Breakout
600 ft	4.4 nm	44 nm
300 ft	2.2 nm	22 nm
100 ft	0.73 nm	7.3 nm

Notes: (1) DBS 1&2 have the same azimuth resolution since they have the same angular resolution and DBS ratio.
(2) The maximum display range for the DBS modes is 40 nm.

Table VIII: Theoretical Display Resolution

Scale (nm)	Resolution (ft)
80	1067
40	533
20	267
10	133
5	67

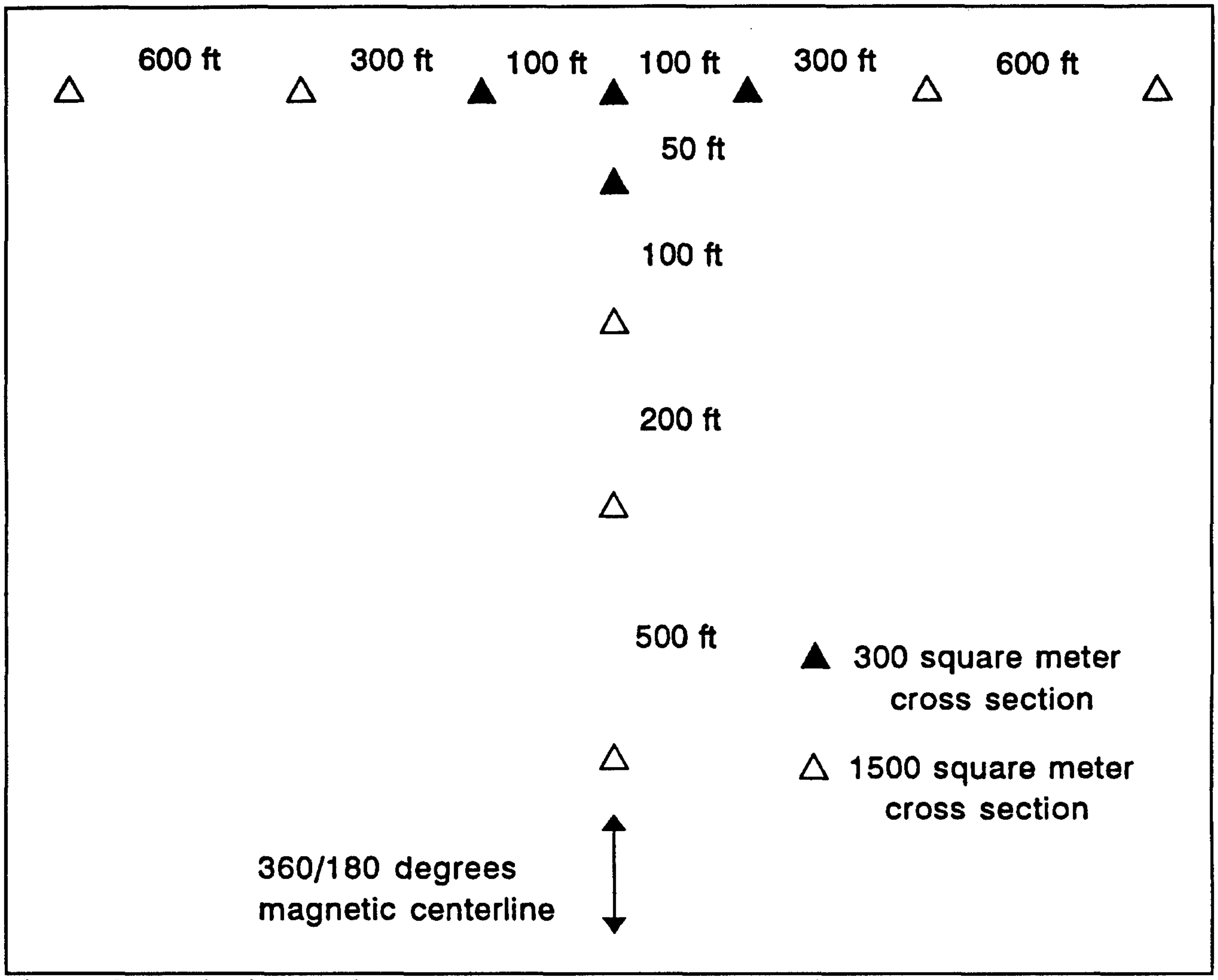


Figure 25: Fictional Air-to-Ground Resolution Array Diagram

Table IX: Comparison of Radar and Display Theoretical Range Resolution

Scale (nm)	Mode	Radar Resolution (ft)	Display Resolution (ft)	Limiting Factor
80	Real Beam	1112	1067	Radar
40	Real Beam	371	533	Display
20	Real Beam	371	267	Radar
10	Real Beam	371	133	Radar
10	DBS 1	148	133	Radar
5	DBS 2	148	67	Radar

Table X: Comparison the Radar and Display Theoretical Azimuth Resolution

Target Separation (ft)	Mode	Target Breakout (nm)	Scale/ Display Resolution (nm/ft)	Limitation
600	Real Beam	4.4	10/133	Radar
300	Real Beam	2.2	10/133	Radar
100	Real Beam	0.73	10/133	<u>Display</u>
600	DBS 1	44	10/133	Radar
300	DBS 1	22	10/133	Radar
100	DBS 1	7.3	10/133	<u>Display</u>
600	DBS 2	44	5/67	Radar
300	DBS 2	22	5/67	Radar
100	DBS 2	7.3	5/67	Radar

Notes: (1) Assumes that the display automatically downscales as the aircraft approaches the target.
(2) The DBS 1&2 radar parameters are the same and so the theoretical radar resolution is the same.

7.2.4. Designing the Test

In general, a radar will never exceed the theoretical limits of resolution as calculated above. Assuming the system was designed to meet the system specification, it is almost certain that the theoretical limits encompass the specification. Bounding the test by the theoretical limits then gives an efficient and sufficient check of the parameter. In this case the theoretical limits provide the maximum reasonable range at which it is necessary to perform each test. Looking at the results listed above, the first array target breakout in the Real Beam Map mode will theoretically occur in range at the edge of the 20 nm display range. The Real Beam Map resolution test will then begin at 20 nm. In the DBS 1&2 modes the theoretical resolution limit predicts that targets will break out in both azimuth and range at the DBS 1&2 maximum operating range of 40 nm and so the DBS 1&2 resolution tests will begin at 40 nm. The test resolution array is presented in figure 27. Due to the flight time constraints, a single data point will be taken per radar mode for a total of three runs inbound to the array.

The reflectors, which make up the sample test resolution array depicted in figure 27 have a 15° horizontal beam width and a 6° vertical beam width within which the test must be performed. Figure 27 is a view looking down upon the array depicting the horizontal beam width limits of the array in terms of the magnetic bearings to and from the array center as well as the array centerline magnetic bearing. As mentioned, figure 28 depicts the vertical beam width limits of the array in terms of aircraft altitude versus range from the array center. The pilot must ensure that the aircraft remains within the airspace defined by the two magnetic bearings from the target shown in figure 27 as well as the range dependent altitude restrictions defined in figure 28. A third restriction is also described in Chapter 2, the DBS mode of operation has a notch over the nose of the aircraft through which the DBS radar detection is not available. As mentioned above, this notch is 7° in width for the sample radar. This means that the pilot can never point the aircraft directly at the array while testing the DBS modes and must "zigzag" inbound to the target within the azimuth limits described above.

In conversation with the test pilot, you determine that 300 KIAS is the best airspeed to perform the test. This airspeed allows for moderate maneuvering while simultaneously performing a descent at a flight path angle of 10° with horizontal. The pilot also mandates a 200 feet AGL minimum altitude for the test as well as VFR conditions. Due to high traffic density in the

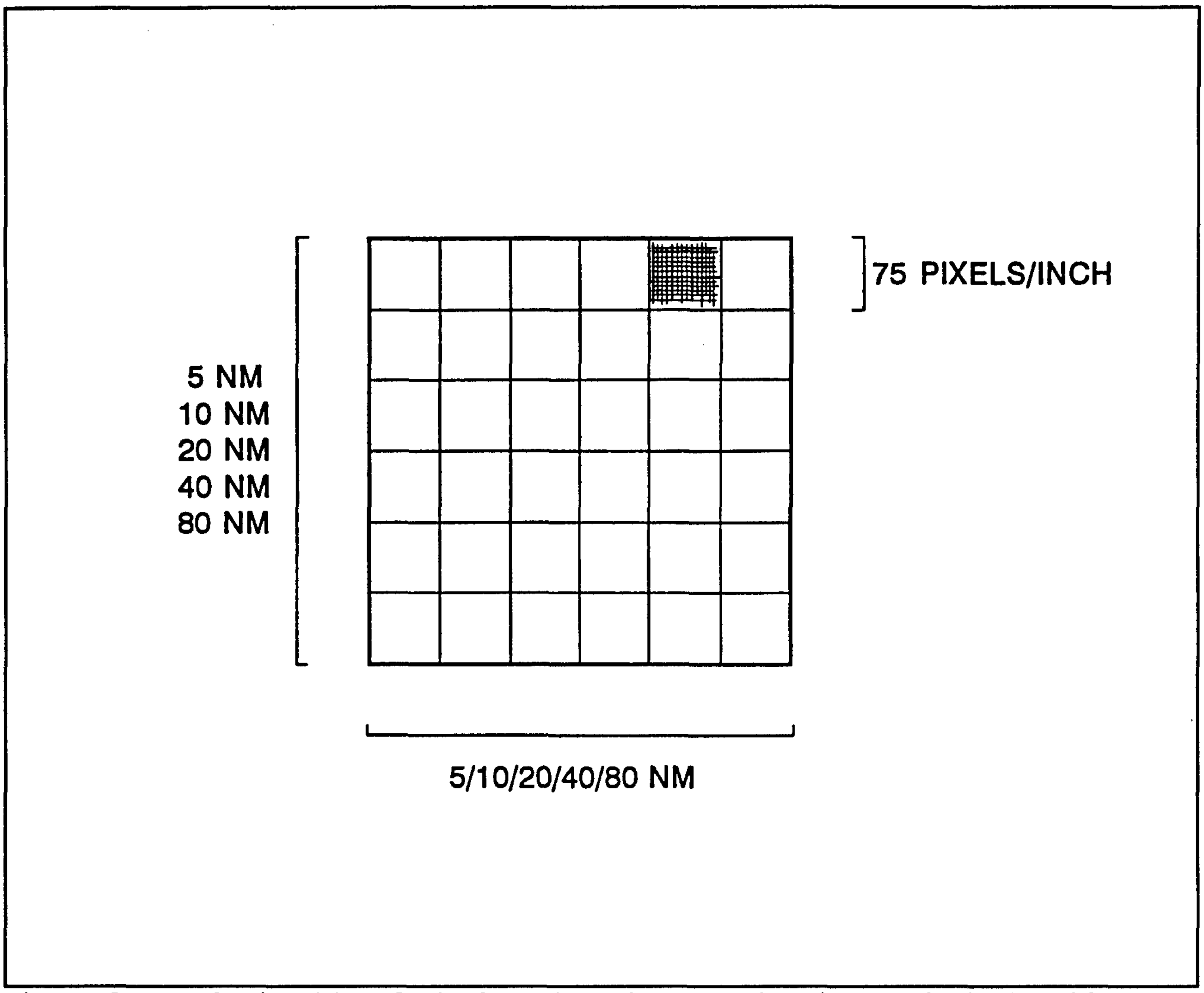


Figure 26: Relationship of Display Dimensions, Scale Sizes and Pixel Grid

working area, he also requires that there be clear visibility for the entire descent to the array, with no cloud layers along the route from the start of the run to the array. The rate of descent in feet per minute will be limited to half the altitude in feet, necessitating a small deviation from the desired flight path angle during the last part of the test, approaching the array. Maneuvering is limited to +3 g and -0.5 g maximums and the pilot in the front seat will act as the pilot at the aircraft controls and will ensure he is looking out of the aircraft for traffic at all times while the pilot in the back seat conducts the test.

Knowing that the vertical centerline of the resolution array is 10° above vertical and that the airspeed over the ground is <u>approximately</u> 6000 feet/nm allows the starting altitude for the data runs beginning at 20 nm and 40 nm from the array to be determined as in equation 37.

$$
\begin{gathered}
ALT = RANGE\,[\tan(10°)] \\
10° = \text{center of array vertical beamwidth} \\
\text{at } 20nm\text{:} \\
ALT = (20nm)[\tan(10°)]\left(6000\frac{ft}{nm}\right) \\
ALT = 21{,}200ft \\
\text{at } 40nm\text{:} \\
ALT = 42{,}300ft
\end{gathered}
\tag{37}
$$

A 300 KIAS airspeed is approximately 5 nm per minute, requiring 4 minutes to complete the 20 nm data run and 8 minutes to complete the 40 nm data runs. The sample array is at sea level and so at the 20 nm beginning range, the 21,200 feet beginning altitude requires a 12,200 ft/4 min=5300 feet/min rate of descent to make the 10° glideslope. The rate of descent is the same for the 40 nm data run since the glide path angle is the same. As a reminder, the flight

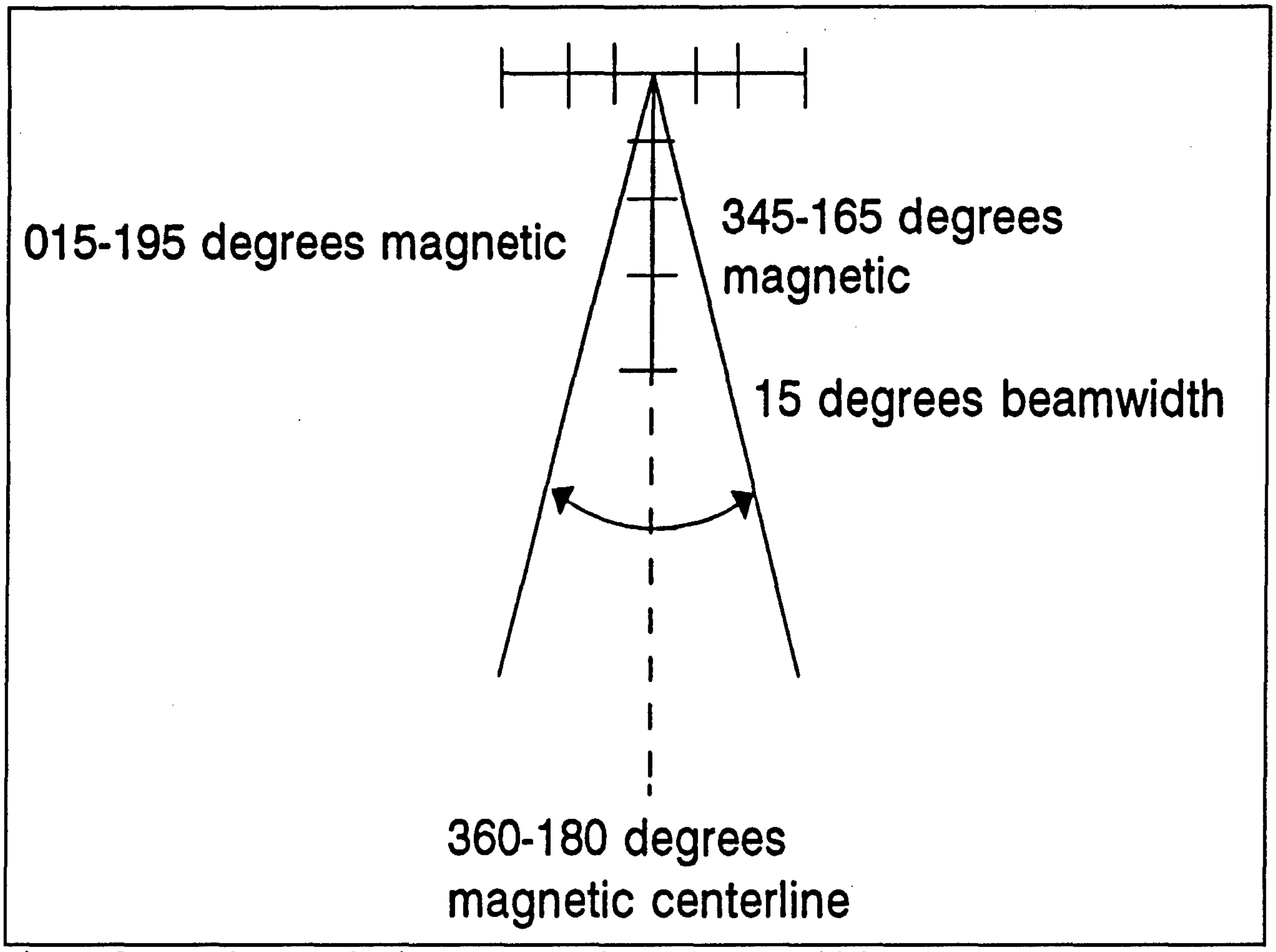


Figure 27: Radar Resolution Array Horizontal Beam Width

path angle will necessarily be deviated from as the rate of descent is shallowed at the lower altitudes and the minimum altitude for the test is approached.

In discussion with the contractor, it is agreed that climb performance data may be taken after takeoff and up to the beginning of the first data run and so the contractor will not begin counting the 30 minutes of flight test time available for resolution measurements until the initial point for the first data run. As outlined above, one 20 nm run and two 40 nm runs are required. Beginning with the 20 nm data point, a single 20 nm inbound run followed by two 40 nm outbound and inbound runs are required for a total of 180 nm. At 5 nm/min, the test will take 36 minutes total, turning the aircraft back over to the contractor over the resolution array at 200 feet AGL. This is 6 minutes? longer than allotted by the contractor; however, after making one last phone call, the contractor agrees to allow the extra 6 minutes.

7.2.5. Data Cards

Cards 75 through 82 are the data cards provided to the project test pilot. Card 1 provides the waypoint definitions to load into the aircraft inertial system to allow quick navigation from the point of aircraft startup (waypoint 0), to the initial point for the 20 nm run (waypoint 1), to the center of the array (waypoint 2) and finally to the initial point for the 40 nm run (waypoint 3). Card 2 is a script for the takeoff and set up for the first data run and card 3 is the data card for the 20 nm data run with the Real Beam Map mode of the radar. Cards 4 through 6 are the script and data cards for the next two runs while cards 7 and 8 depict the horizontal and vertical layout of the array and the flight path requirements. Card 9 is possibly the most important card in that it provides a full page of note taking space for incidental information.

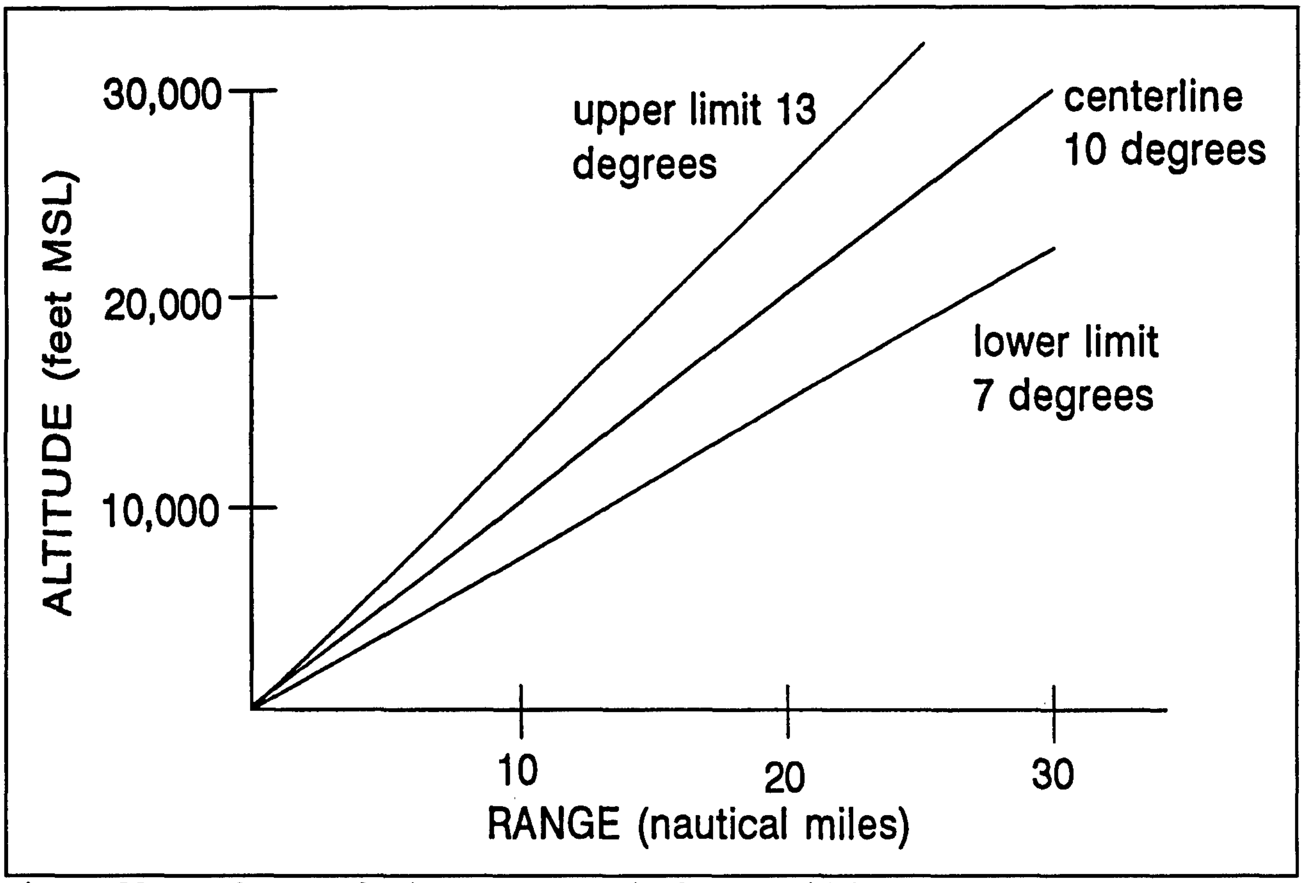


Figure 28: Radar Resolution Array Vertical Beam Width

CARD NUMBER 1

WAYPOINTS

(0) N 38° 00′ W 123° 00′ HOMEPLATE

(1) N 38° xx′ W 123° xx′

(2) N 38° yy′ W 123° yy′

(3) N 38° zz′ w 123° zz′

Card 75: Case Study Data Card 1

DATA CARD 2

F/A-XX RADAR RESOLUTION TEST

-TAKEOFF AND PROCEED TO WP 1

-SET 300 KIAS

-CLIMB TO 21,200 FEET MSL

-CROSS WP 1 INBOUND TO THE ARRAY AT WP 2 HEADING 360°

-SET A 5300 FT/MIN RATE OF DESCENT AND REMAIN IN THE GLIDESLOPE BAND

-PLACE THE RADAR IN THE REAL BEAM MAP MODE, BEGIN IN A 40 NM SCALE

-DESIGNATE THE ARRAY IN THE GEOSTABLE MODE AND EXPECT THE DISPLAY TO AUTO DOWNSCALE

-KEEP THE ARRAY WITHIN 353° -007°

-OBSERVE A MINIMUM ALTITUDE OF 200 FEET AGL

-OVERHEAD THE TARGET, TURN OUTBOUND TO WP 3

Card 76: Case Study Data Card 2

DATA CARD 3

RUN NUMBER 1

REAL BEAM MODE

MAX NUMBER OF RANGE TARGETS	RANGE AT TARGET BREAKOUTS		
	2	4	6

NOTES:

Card 77: Case Study Data Card 3

DATA CARD 4

-CLIMB TO 42,300 FEET MSL

-CROSS WP 3 INBOUND TO THE TARGET, WP 2, HEADING 360°

-SET 5300 FT/MIN RATE OF DESCENT AND REMAIN IN THE GLIDE SLOPE BAND

-SET THE RADAR TO DBS 1 MODE

-DESIGNATE THE ARRAY USING THE GEOSTABLE MODE

-KEEP THE ARRAY WITHIN 353° TO 007°

-KEEP THE ARRAY OUT OF THE NOTCH

-OBSERVE A MINIMUM ALTITUDE OF 200 FEET AGL

-OVERHEAD THE TARGET TURN OUTBOUND TO WP 3

-REPEAT IN THE DBS 2 MODE

Card 78: Case Study Card 4

DATA CARD 5

RUN NUMBER 2

DBS 1 MODE

MAX NUMBER OF RANGE TARGETS	RANGE AT TARGET BREAKOUTS		
	2	4	6

NOTES:

Card 79: Case Study Card 5

DATA CARD 6

RUN NUMBER 3

DBS 2 MODE

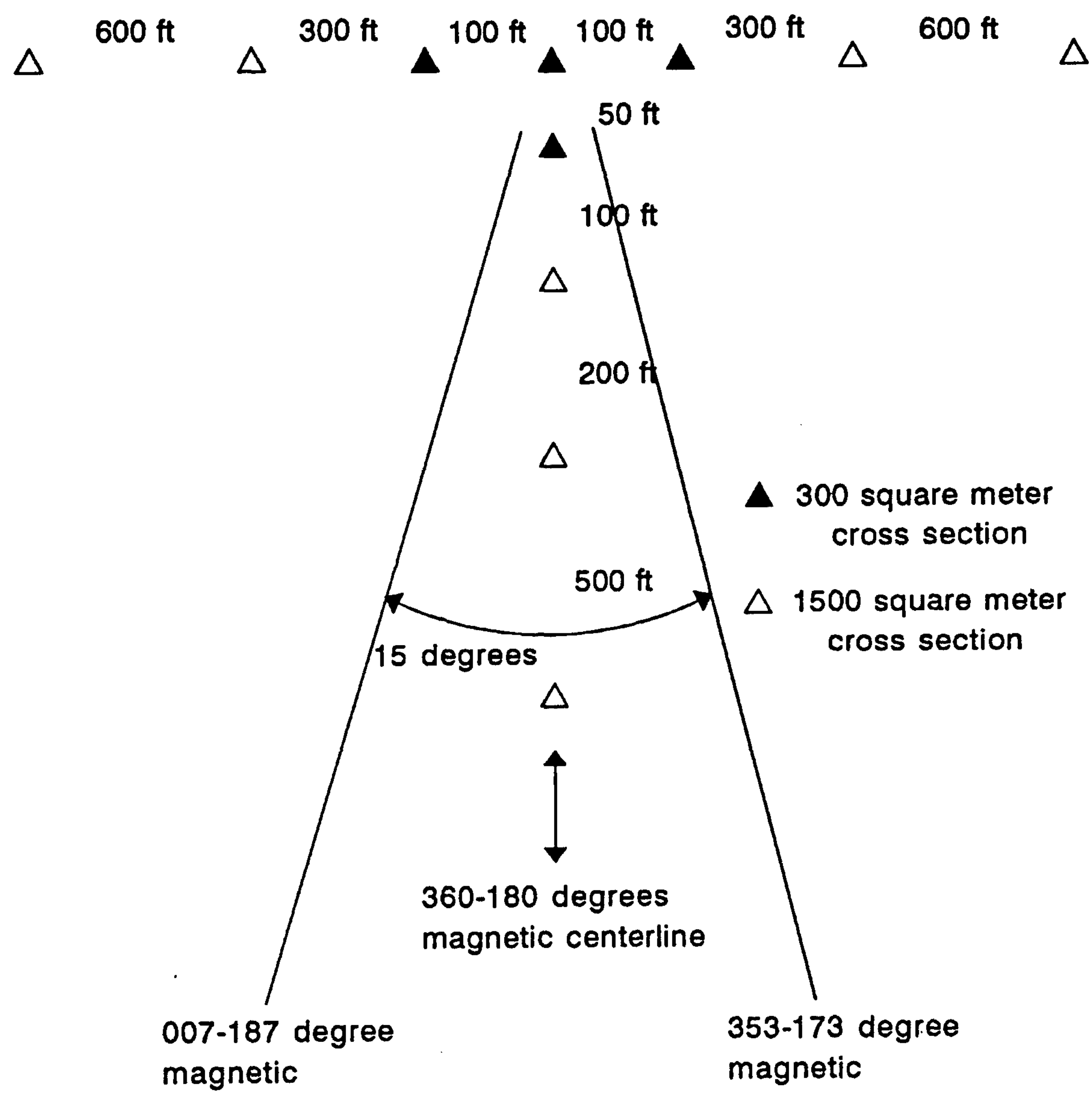
MAX NUMBER OF RANGE TARGETS	RANGE AT TARGET BREAKOUTS		
	2	4	6

NOTES:

Card 80: Case Study Card 6

CARD NUMBER 7

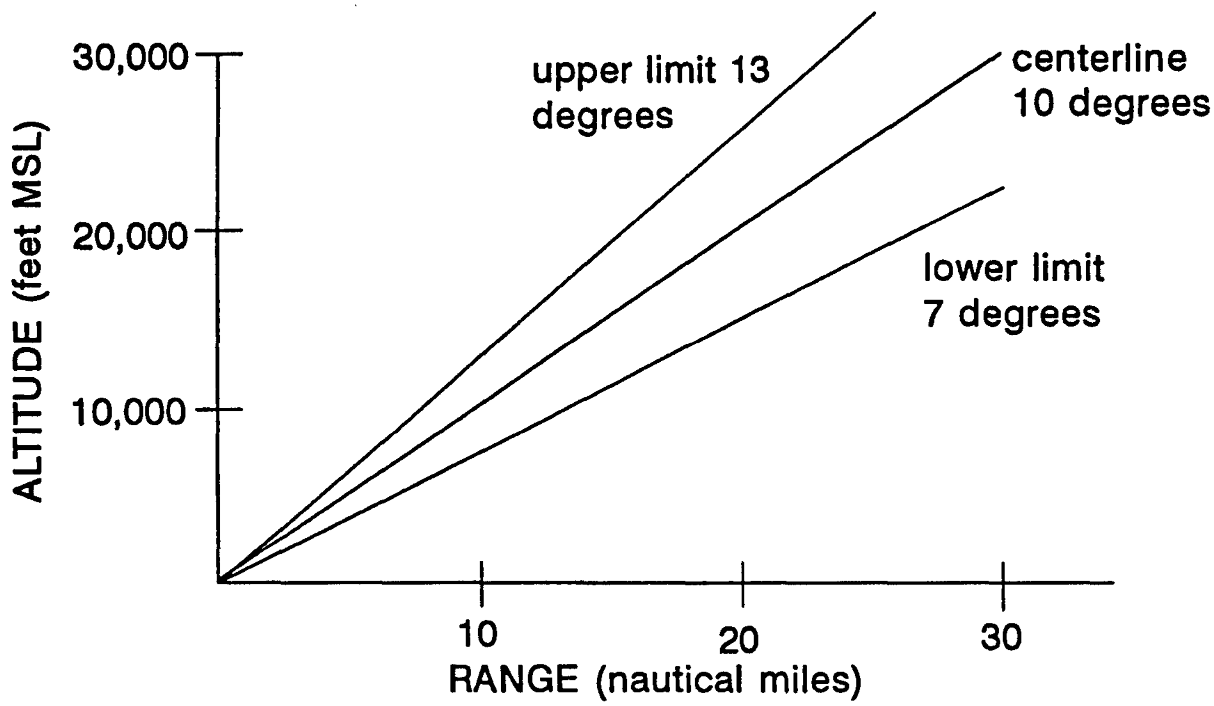
ARRAY DIAGRAM



Card 81: Case Study Card 7

DATA CARD 8

ALTITUDE BAND



$5300 \frac{FT}{MIN}$; 300 *KIAS*
ON GLIDESLOPE
$\gamma = 10°$

7.2.6. Summary

This case study has demonstrated a couple of important points. First, the simple techniques described in the previous sections are useful for real world application and are adequate for a wide range of quick measurements. What some of the tests lack in precision and documentation, they make up in accessibility and ease of implementation. Adding more instrumentation and complexity to the test changes the basic technique very little and merely enhances the data collection process with automatic and sometimes more precise data. Second, the case study demonstrated the criticality of fully understanding the workings of the system under test. Without a thorough knowledge of the theoretical resolution limits of the radar under test, it may have been necessary to test the resolution out to the display limits of the radar, wasting flight time and thus money.

8.0. CONCLUSIONS AND RECOMMENDATIONS

These test techniques should be used as a generalized baseline for the development of specialized tests for new systems. A basic knowledge of system theory and the characteristics of the test article are assumed. All the techniques presented are as simple as possible and require a minimum of outside assets. Better and more exact methods exist; however, most merely involve scaling up the techniques presented here, usually in the form of more sophisticated and precise truth data (time/space positioning data, telemetry, onboard instrumentation, etc.). Using the methods presented here, the test pilot should be able, in just a few flights, to make a good qualitative assessment of the system under test and have adequate numerical data to support his or her assessment. Although not suitable in some test programs, this level of data accuracy is often sufficient. More important than the exact test procedure presented, is the methodical, common sense thought process required for test planning. Understanding the development of the simple tests presented here for the sample systems will enable the evaluator to develop his or her own procedures for systems and functions not covered by this document.

During the development of the techniques presented here, frequent license was permitted in the selection of test ranges, speeds, altitudes, etc. It cannot be overemphasized that the details of the test must be specific to the needs of the system and platform under test. It is intended that the numbers presented will give the reader a flavor for the requirements of the fictitious sample systems and platforms, enabling him or her to then choose test points and conditions for other systems. One final point must be stressed. Every detail of each individual test, as well as the order and precedence, must be thought through and planned before the flight and then the plan must be flown, if usable data is to be consistently obtained.

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